BEHAVIOR OF WIDE PLATES UNDER EDGE COMPRESSION

Philippe Cheney Gaucher

and

Sherman Clark Reed

STITUTE OF TECHNOLOGY

Naval Architecture
e Engineering

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by

and S. C. Reed

May 1955

Thesis accomplished as part of Project S-9, Buckling Strength of Hull Structures, under the auspices of the Society of Naval Architects and Marine Engineers.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Naval Architecture
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ABSTRACT

BEHAVIOR OF WIDE PLATES UNDER EDGE COMPRESSION

by

Philippe C. Gaucher and Sherman C. Reed

Submitted to the Department of Naval Architecture and Marine Engineering on May 23, 1955 in partial fulfillment of the requirements for the degree of Naval Engineer.

This investigation constitutes a continuation of a program being carried out in the Department of Naval Architecture and Marine Engineering under the auspices of the Society of Naval Architects and Marine Engineers. Work was started by Pittman and Rinehart in 1953 and their thesis of May 1954 entitled "On Providing Uniform Edge Compressive Loads for Wide Flat Plates" should be consulted in conjunction with this thesis. This is necessary to obtain continuity of the work progressed thus far.

The apparatus was designed by Pittman and Rinehart for use in a 300,000 pound tensile testing machine. This machine proved to be unstable at compressive loads above 50,000 pounds. Therefore, the original apparatus was modified as follows: (1) the loading heads were connected by 1" steel plates, (2) the load equalizing rams were also used to apply the load to the test plate, reaction being through the heads such that the 1" steel plates were in tension and (3) a load measuring system consisting of load cells using electric resistance strain gages, the cells being placed between ram and plate.

The test specimens were the plates procured by Pittman and Rinehart, which represent one-quarter scale panels of 1020 steel such as are used on transversely framed ships.

The object was to compare the experimental results to the theoretical predictions, both for verification and for scale effects. Hitherto there have been no experimental investigations of panels with aspect ratios of the plates to be tested.

As a result of the work thus far accomplished, the following general conclusions are drawn:

1. No scale effect is apparent.
2. Initial curvature and eccentricity seriously affect the buckling strength of a plate. The method of testing makes it difficult to separate the two factors. Furthermore, extrapolating to eliminate these effects as is common in slender column work does not appear completely justified.

3. The predictions of Bleich are generally supported. However, some of the tests results were below theoretical values by as much as 40%.

4. The surface condition of the plate is an important factor affecting the results. Data obtained from plate series having uniform, shallow pits as a result of shot-blasting showed a marked degree of consistency compared to those having wide variations of surface conditions.

5. In the set-up used, the following are the predominant factors affecting experimental results.

   (a) Eccentricity

   (b) Initial plate curvature

   (c) Load measuring instrumentation

   (d) Speed of load application

   (e) Determination of effective thickness.

3. The predictions ...
some of the ...
when as 10%.

4. The surface ...
...
uniform ...
...

Cambridge, Massachusetts
May 23, 1955

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the requirements of the degree of Naval Engineer, we herewith submit a thesis entitled "Behavior of Wide Plates Under Edge Compression."

Respectfully,

Philippe C. Gaucher
Lieutenant, U.S. Coast Guard

Sherman C. Reed
Lieutenant (junior grade), U.S. Navy

BEHAVIOR OF WIDE PLATES UNDER
EDGE COMPRESSION

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NOTATION

a -actual plate dimension in line with the applied load

b -unsupported length of plate between a edge supports

b' -actual width of plate

l -length of test specimen used to determine modulus of elasticity

t -plate thickness measure by micrometer

t' -plate thickness t less depth of pits

w -width of test specimen used to determine modulus of elasticity

A -plate cross-sectional area based on t and b

A' -plate cross-sectional area based on t' and b

E -modulus of elasticity

GF -gage factor

K -constant used to determine critical stress dependent on plate dimensions and edge conditions

P -applied load

P_{ult} -ultimate load carried by the plate

R -Huggenberger tensometer scale reading

δ -difference of strains on opposite faces at the center of the plate

ε_1 -strain in top surface of plate as measured by top strain gage

ε_2 -strain in bottom surface of plate as measured by bottom strain gage

ε_a -average strain at center of plate as determined from ε_1 and ε_2

σ -unit load in plate called stress

σ_{CR} -critical stress determined by various methods of data analysis or by theoretical calculation

σ_p -proportional limit of the material

σ_{ULT} -maximum stress carried by plate during buckling test

ν -Poisson's ratio - assumed to be 0.3

I. INTRODUCTION

A. General

The purpose of this investigation was to continue the research project started by Pittman and Rinehart [5]. The Hull Structures Committee of The Society of Naval Architects and Marine Engineers is sponsoring this project to provide experimental verification of the theoretical buckling and ultimate strengths of plating panels commonly used in the shells of transversely framed ships.

For the purposes of such experimental work, the framing behind the shell plating of ships divides the plating into individual panels having a variety of edge conditions. Each panel may be acted upon by direct axial loads, shear forces, and/or moments along either or both edges. In addition, the panels may be subjected to pressure forces normal to the plane of the plate. Variables which affect the plate strength are: (1) the plate length to thickness ratio; (2) the plate length to width ratio; (3) the degree of plate edge rotational restraint; (4) the panel boundary stiffness; (5) the effect of non-uniform distribution of load. It has been concluded by work already performed on this project [5] that small variations of the "uniformly" distributed load have no appreciable effect on the buckling strength of the plate.

B. Status of Project

The program as outlined by Pittman and Rinehart to carry out the objectives of the sponsor is repeated below [5]:

Phase I - To make a survey of the literature relating to the theoretical buckling and ultimate strengths and experimental work thereon; to determine the ranges of parameters for which experimental data was lacking or insufficient; and to find information

upon the effect and growth of unfairness.

Phase II - To conduct buckling and ultimate strength tests for uniaxial edge compression on plates of such dimensions as are indicated by Phase I, with loaded and unloaded edges simply supported.

Phase III - To conduct buckling and ultimate strength tests for uniaxial edge compression on plates of such dimensions as are indicated by Phase I, with unloaded edges simply supported and loaded edges elastically restrained to varying degrees.

Phase IV - To design, build, and evaluate a test apparatus for the accomplishment of Phases II and III.

Pittman and Rinehart completed Phase I, and started Phase II by buckling one set of four plates. It was originally thought by the authors that Phase IV had already been completed, since the work done on Phase II was successful. Therefore, original plans for continuing the investigation called for completion of Phase II, and preliminary work in Phase III. However, the 300,000 pound test machine with which the complicated plate jig was loaded proved to supply insufficient lateral support at other than low loads, thereby preventing the testing of a majority of the plates. Therefore, the authors were forced to design a 280,000 pound test machine using Pittman and Rinehart's jig. This task was successfully carried out, and plates of representative size composing one-half of the contemplated series of Phase II have been tested.

C. Literature Survey

In order to carry out as much of the research project as possible, the collection and interpretation of work existing in the field of

investigation was accepted. No preliminary literature survey was carried out, and only such literature that pertained to particular problems was consulted.

D. Work Accomplished

In the previously designed test apparatus, sufficient lateral restraint was lacking above approximately 50,000 pounds load, even though considerable redesign was made of the lateral supports. A new machine employing the original jig from head to head was designed and built. The whole assemblage was laid on its side changing original conditions by only a small amount (See Appendix B). A hydraulic load and control system was selected which used the rams of the original jig. A load measuring system composed of seven load cells was designed and built to accuracy standards commensurate with the varying ultimate loads expected.

Simply supported plates as listed in Table I were buckled and ultimate loads recorded. Bending data was taken at suitable increments of load during each test. Only one plate of the 50-1/4 series was tested, the remaining three having been rendered useless in the original test apparatus.

TABLE I

Dimensions of Plates Tested

Plate Designation*	a (in.)	b** (in.)	t (in.)	a/t (in/in)	a/b (in/in)
40-1/4-1	10.188	43.8	0.268	38.0	0.232
2	"	"	0.262	38.8	"
3	"	"	0.264	38.6	"
4	"	"	0.258	39.4	"
50-1/4-4	"	"	0.222	45.8	"
50-1/3-1	"	32.8	0.226	45.0	0.310
2	"	"	0.229	44.4	"
3	"	"	0.216	47.1	"
4	"	"	0.222	45.8	"
50-1/2-1	"	21.9	0.222	"	0.465
2	"	"	0.211	48.2	"
3	"	"	0.211	"	"
4	"	"	0.218	46.6	"
70-1/4-1	"	43.8	0.158	64.4	0.232
2	"	"	0.158	"	"
3	"	"	0.158	"	"
4	"	"	0.158	"	"
70-1/3-1	"	32.8	0.161	63.2	0.310
2	"	"	0.162	62.8	"
3	"	"	0.158	64.4	"
4	"	"	0.158	"	"
70-1/2-1	"	21.9	0.154	66.1	0.465
2	"	"	0.154	"	"
3	"	"	0.154	"	"
4	"	"	0.154	"	"

Note: All plates cut from rolled ship plate of 1020 steel. Each thickness cut from the same rolled plate, laid out in the same direction.

* Plate designation numbers refer to nominal a/t - nominal a/b - plate number.

** The "b" dimension (unsupported length of the plate) is the overall dimension "b'" less 0.5 inches.

II. PROCEDURE

A. General

The continuation of the plate buckling program presented various problems. A means of measuring, applying, and controlling loads was necessary to obtain the desired data. Furthermore, simple edge support on all four edges had to be maintained; variations from uniform stress distribution had to be minimized; all four plate edges had to be maintained in the same plane; and eccentricities of plate loading had to be minimized. The insufficient lateral restraint provided by the original apparatus necessitated reconsideration of all the above problems.

B. Lateral Restraint

Movement of the test plate and ballbearing raceways normal to the applied load could not be prevented satisfactorily above 50,000 pounds load in the apparatus as originally designed [5]. For this reason, a new rig was designed which eliminated the original 300,000 pound test machine entirely. The new rig was set up on the newly built test bed in the Ship Structures Laboratory of Building 41. By placing the original rig on its side, it was easy to attain adequate restraint in all directions (see Fig. 27).

The 18" wide-flange I-beams which served as test heads were prevented from moving apart by connecting them with a system of bed plates and stop plates which were bolted together, and which were in turn bolted to the test bed. Movement of the test specimen normal to the load was prevented by insertion of blocking between the ballbearing raceways and the bed plates. I-beams wedged with hardwood shims were used for this purpose.

C. Load Application

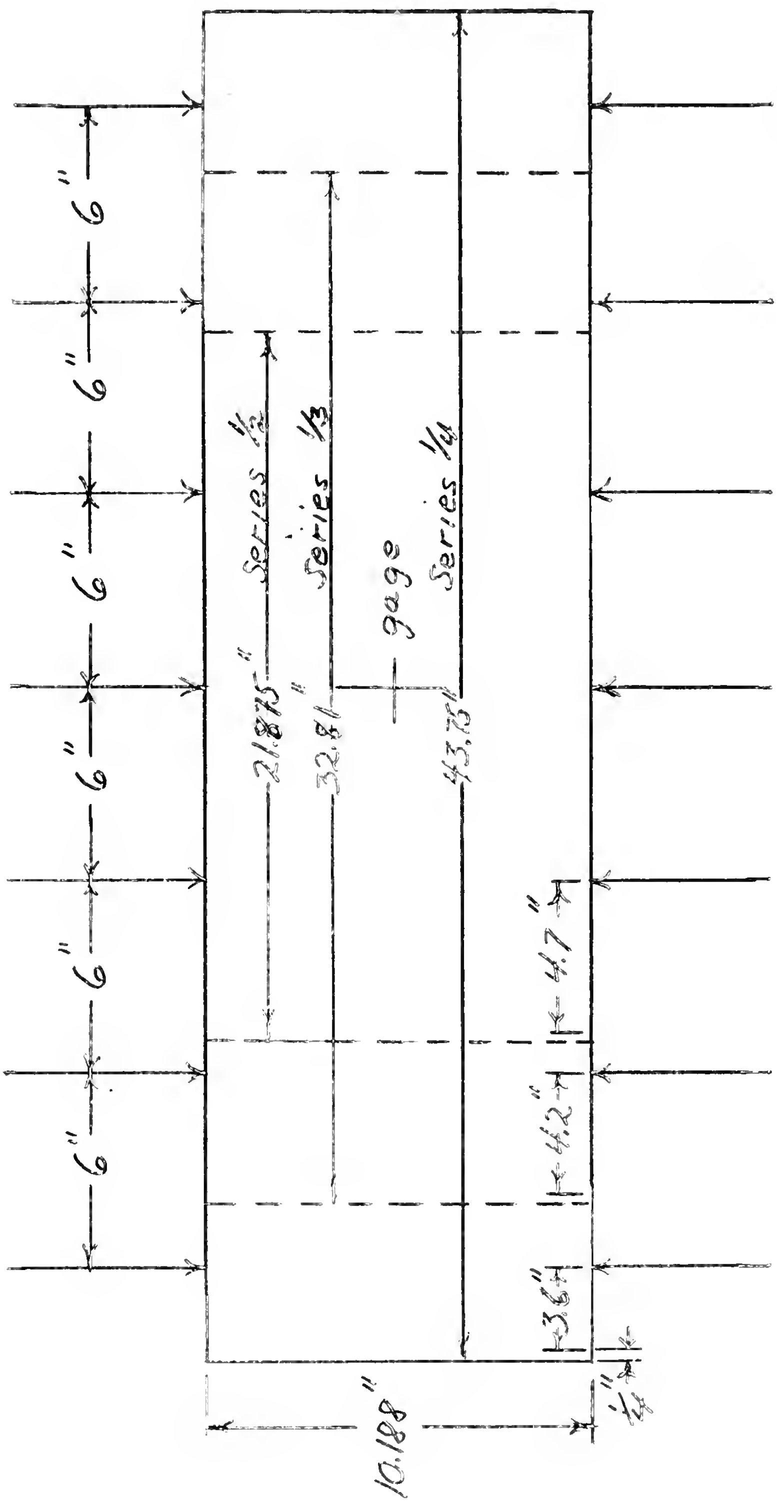
The original system for providing uniform load distribution was inherently capable of applying load. However, the limited travel of the rams and the necessity for allowing for ram compression under load made a system of gross adjustment of the distance between test heads necessary. This was accomplished by drilling bolt holes in the bed plates so that one set of stop plates could be moved in 4" steps (see Fig. 27).

A compromise was made about ram spacing. The minimum length of plate which could be tested with seven rams was approximately 26". The maximum length of plate tested was 44.25" which necessitated a ram spacing of six inches between centers (see Fig. 1). Consideration of load measuring sensitivity discussed in Section D meant that, for low buckling loads, the number of rams applying the load should be small. Consideration of these requirements resulted in maintaining ram spacing at six inches for all plates tested. All fourteen rams (seven on each load edge) were used in buckling plate series 40-1/4, 50-1/4, and 70-1/4. Four end rams were inactivated and the remaining ten rams were used for plate series 50-1/3 and 70-1/3. Four more end rams were inactivated and the remaining six rams were used for plate sizes 50-1/2 and 70-1/2.

Load was applied by using a Blackhawk P-182 electric hydraulic high pressure pump (see Fig. 26). The pump was connected to the manifold of one set of rams, that carrying the load cells, while the remaining set of rams received the load indirectly through the test plate. The pump was controlled by using the bypass valve for variable control, and the needle valve for positive shut off.

The hardened steel loading bars were supported by loading bar clamps on the end rams only. For plate series 50-1/2 and 70-1/2, only

Figure 1
Ram Locations



4/27/55 ACP.

the lower half of these clamps were used to avoid interference with the electrical connections on the load cells. Extreme care was taken to insure that the lines of action of both sets of rams were in the same plane. This alignment was determined by using a spirit level on the ram bodies and on a line joining the centers of the milled slots of the hardened steel loading bars. On one occasion the top bed plates were checked to assure that the rig was maintaining its planar configuration. A six-foot steel straight edge was placed on the bed plates while holding the load at 220,000 pounds. The bed plates were straight and horizontal.

D. Load Measurement

Load cells placed between the ram heads and the hardened steel loading bar of one set of rams provided a means of measuring the actual load applied to the test specimen, exclusive of ram friction and retraction spring effects. The additional unsupported length necessary for the load cells was compensated for by rigidly attaching the load cell to the ram head, and by providing further lateral support to the ram bodies (see Figs. 27 and 32).

Although several other systems were tried, the plate loadings were measured by using only three electrically active load cells. Electrical difficulties encountered in a seven load cell series-parallel system necessitated the use of the three load cell system. (See Appendix E.) The remaining load cells were used as ram extensions in the ten and fourteen ram loading systems. Each load cell has two axial and two circumferential electric resistance strain gages arranged so as to give a maximum strain reading for a given load. The corresponding gages of each load cell were wired in series, and each set placed in the four

arms of a Wheatstone bridge so as to provide approximately 2.6 times the sensitivity of a single axial gage. The series arrangement of gages averaged the loads of the three center rams to which the active load cells were attached. The external Wheatstone bridge was connected to a Baldwin Strain Indicator (Type L) which was used with a gage factor setting of 1.77 (the minimum) so as to give maximum sensitivity.

No attempt was made to correlate actual strain in the load cells with total load since the effects of load distribution within the cell were unknown. The total load on the machine was derived from the load cell strain by using calibration data. The three active load cells together with the rams to which they were to be attached were calibrated on the 300,000 pound test machine (M.I.T. #105). During calibration, the three rams and their load cells were placed on the 18" wide-flange I-beam on the lower head of the test machine. One hardened steel loading bar was laid on top of the load cells, and a 1/2" round bar was placed in the milled concavity of the loading bar to simulate the concentrated loading of the plate edge segments. The upper head had no rams attached and consisted merely of the other 18" wide-flange I-beam. No lateral restraint was applied or needed. The electrical system was identical to that used for buckling plates.

The load cells were calibrated against the 150,000 pound gage of the 300,000 pound test machine. This gage is accurate to 1/2% of total load (750 pounds). These runs were made to maximum total loads of 95,000 pounds. Sizeable creep at high loads was eliminated by cycling the load cells several times to maximum load. This creep at high loads had to be removed before each series of plates tested since periods of inactivity caused it to return. It was ascertained during calibration

tests that a repeatable strain indicator zero indicated that the creep characteristic had been removed for a particular run. It was later determined that the creep phenomenon did not return in any appreciable amount for four hours (See Appendix E).

Some runs were made to 50,000 pounds total load to check load measuring accuracy. Further runs were made up to 30,000 pounds using the testing machine's 30,000 pound load gage to determine the characteristics of the calibration curve near zero load. Data was sufficiently linear to permit use of a simple ratio of 1694 micro-inches per inch for 95,000 pounds total load. Number one load cell was checked to determine the effects of the load concentration. This load cell was not one of those actually used for plate buckling tests, however.

The hydraulic pressure in the ram system was recorded during the calibration runs using a 10,000 psi Blackhawk Z-720 pressure gage having one division per 100 psi. This gage was connected to the hydraulic line between the pump needle valve and the ram manifold.

Recalibration of the load cells after the plates were tested was not carried out due to lack of time. No difficulty is anticipated in carrying this out at a later date.

E. Test Preparation

All plates were ground down to the bottom of their pits on both sides at the geometrical center to permit good adherence of strain gages. The plate surfaces near all edges were lightly ground to remove mill scale. Two strain gages were glued to the plate on opposite sides of the plate's geometric center, oriented parallel to the applied load.

Plate thickness was measured by taking at least twenty random samples with a Starrett #436 micrometer about 1/2" in from all edges.

Pit depth was measured on both sides by using an Ames 88 dial indicator equipped with a special sharpened point. The flatness of the plates was determined by laying the plate against a vertical straight-edge, and measuring the maximum variation by using a ruler accurate to 1/64". This measurement was called degree of unfairness and the curvature was confirmed by eye to be a smooth arc except as noted. Overall plate dimensions were checked by using a steel tape accurate to 1/32", but measurements determined by Pittman and Rinehart were actually used.

The plates were placed in the ball-bearing raceways concave downward. The load bearing segments were affixed to the B-edges by using single lengths of resin-core solder and spring steel shims as described by Pittman and Rinehart [5]. The load bearing segments were loosely shimmed concentrically, but the size of shims required varied within each plate series. Actual sizes were not recorded.

Before testing on a given day an 8" x 8" wide flange I-beam, specially bracketed to withstand high loads, and with a one-inch round bar attached to either flange to simulate test specimen conditions (see Figs. 31 and 32), was inserted between the hardened steel loading bars. Hardwood blocks were used to wedge the H-beam into proper alignment and to prevent side sway. The test machine was then cycled a sufficient number of times to obtain a strain indicator zero, repeatable within 20 micro-inches per inch. After cycling was completed, the H-beam was removed and the union of the rams and load cells was checked for looseness.

The prepared test specimen was then carefully inserted into the machine and pushed against the unretracted rams. The other pair of 4" I-beams were then inserted and the whole test specimen assembly was aligned by the use of hardwood shims. For long plates which sagged due

to their own weight, a light wire sling attached to a chain fall was used to lift them into alignment. The sling was cast off after sufficient load had been applied to center the B-edges into the milled grooves of the hardened steel loading bars (except for one test).

Except for the first plate tested, the two strain gages on the plate were each connected to a separate Baldwin Strain Indicator. An alternate switching system was used with a single strain indicator for the first plate. A 3" angle with one planed edge was used as a track over the top two bed plates for a dial indicator. The dial indicator was equipped with a 5" probe to take the deflection measurements of the plate at the edge near the load cells. The deflection measurement system was used for plate series 50-1/2, 70-1/3, 70-1/2, and 50-1/3-3.

F. Buckling Tests

Zeros were taken on all three strain indicators when retraction of the rams showed no further change in the load strain indicator. Solder gaskets were then set at some arbitrary proportion of total expected buckling load. This averaged between 300 to 500 psi on the pressure gage. New strain indicator zeros were then taken after the load was released.

The load was applied by using a P-182 high-pressure electric pump controlled by the by-pass valve. The "master" instrument was always the load strain indicator. The galvanometer of this strain indicator provided a very sensitive indication for the pump operator. The other two strain indicators were simultaneously and continuously balanced during load application, except where it was physically impossible during the latter part of each test. Here the time required for simultaneous balance caused considerably more interruption in the smooth application

of load. In one case, a run was made while allowing full yield at each loading. Pump overheating prevented further employment of this method.

Test runs were discontinued and the ultimate loads recorded when total load began to decrease. The rams were then retracted and the load strain indicator zero recorded. In most cases, plate strain gages were broken by the test and no zero could be recorded.

III. RESULTS

Buckling Tests

Twenty-five plate specimens were tested to ultimate failure. The ultimate loads are shown in Table II. The bending curves based on applied load versus strain-difference are shown in Figures 2 through 8 in Section IV.

The failure of each plate was noted to be one noded in both a and b directions.

Two strain gages were placed at the geometrical center of the plate, one on each side, opposite each other. The difference of these strain gage readings is a measure of the bending in the plate.

TABLE II-A

Results of Buckling Tests

Plate Designation	Young's Modulus (psi)	Ultimate Load (Kips)
40 - 1/4 - 1	30,200,000	190.8
2	"	176.6
3	"	206.8
4	"	160.2
50 - 1/4 - 4	"	101.3
50 - 1/3 - 1	"	109.2
2	"	96.5
3	"	87.6
4	"	85.0
50 - 1/2 - 1	"	72.1
2	"	81.8
3	"	65.5
4	"	68.6
70 - 1/4 - 1	28,300,000	37.7
2	"	53.8
3	"	44.6
4	"	49.1
70 - 1/3 - 1	"	33.5
2	"	32.2
3	"	33.0
4	"	35.2
70 - 1/2 - 1	"	35.0
2	"	38.8
3	"	38.0
4	"	44.4

TABLE II-B

Buckling Tests
(based on t)

Plate Desig.	σ_{ult} (exp) (Ksi)	σ_{cr} (theor) (Ksi)	σ_{cr} (T.O.K.) (Ksi)	σ_{cr} (Donnell) (Ksi)	σ_{cr} (Southwell) (Ksi)
40-1/4-1	16.22	21.15	15.1	17.5	17.4
2	15.39	20.15	14.0	17.2	17.0
3	17.85	20.50	16.2	20.6	20.1
4	14.17	19.55	10.9	16.7	16.8
50-1/4-4	10.43	14.48	9.8	11.8	11.8
50-1/3-1	14.73	16.10	14.0	15.6	14.7
2	12.84	16.51	11.4	14.2	14.2
3	12.39	14.70	11.7	12.3	11.8
4	11.67	15.52	10.4	13.1	13.2
50-1/2-1	14.83	19.18	13.1	15.5	15.2
2	17.71	17.31	16.6	18.2	18.3
3	14.19	17.31	13.7	16.1	16.2
4	14.42	18.48	13.1	17.4	17.9
70-1/4-1	5.44	6.88	4.26	6.39	6.27
2	7.78	6.88	6.65	7.81	8.00
3	6.45	6.88	5.65	6.58	7.30
4	7.09	6.88	6.51	7.30	8.21
70-1/3-1	6.34	7.68	5.70	6.70	6.81
2	6.05	7.76	4.62	6.46	6.28
3	6.37	7.37	5.77	7.07	7.10
4	7.05	7.37	6.31	7.20	7.13
70-1/2-1	10.38	8.66	9.62	13.4	12.9
2	11.51	8.66	10.10	13.6	13.5
3	11.27	8.66	10.30	13.5	13.4
4	13.18	8.66	11.90	15.0	15.4

TABLE II-C

Buckling Tests
(based on t')

Plate Desig.	σ_{ult} (exp) (Ksi)	σ_{cr} (theor) (Ksi)	σ_{cr} (T.O.K.) (Ksi)	σ_{cr} (Donnell) (Ksi)	σ_{cr} (Southwell) (Ksi)
40-1/4-1	18.75	15.81	17.4	20.3	20.1
2	18.16	14.50	16.5	20.3	20.1
3	19.48	17.20	17.6	22.5	21.9
4	15.27	16.90	11.8	17.9	18.0
50-1/4-4	11.12	12.72	10.5	12.6	12.6
50-1/3-1	16.09	13.51	15.2	17.0	16.1
2	13.55	14.87	12.0	14.9	14.9
3	13.22	12.90	12.5	12.5	13.1
4	12.36	13.90	11.0	13.9	13.8
50-1/2-1	16.40	15.72	14.5	16.8	17.1
2	19.77	13.89	18.5	20.3	20.3
3	15.46	14.62	14.9	17.6	17.6
4	15.21	16.50	13.8	18.4	18.9
70-1/4-1	5.74	6.22	4.50	6.72	6.61
2	8.19	6.22	7.01	8.44	8.24
3	6.79	6.22	5.95	7.00	7.70
4	7.48	6.22	6.87	7.69	8.67
70-1/3-1	6.59	7.10	5.92	6.97	7.08
2	6.22	7.38	4.75	6.64	6.44
3	6.62	6.84	5.99	7.34	7.38
4	7.07	6.84	6.56	7.48	7.39
70-1/2-1	10.93	7.77	10.1	14.1	13.6
2	12.20	7.66	10.7	14.4	14.3
3	11.72	7.96	10.7	14.0	14.0
4	13.87	7.78	12.5	15.8	16.2

IV. DISCUSSION OF RESULTS

A. General

The interpretation of any plate buckling data is a subject for considerable discussion because of the large numbers of variables that may effect the plate critical strength. To aid in the proper evaluation of results, each plate was considered individually and bending curves drawn (Figures 2-8). These curves were analysed using the "top-of-the-knee" method [5] to obtain critical buckling stress. Donnell's and Southwell's methods were also used to obtain another value of critical buckling stress (Figures 8-20). Theoretical buckling stresses using formulae from Bleich and Ramsey [2] were calculated for each plate using experimental values of the modulus of elasticity. No plates of the series tested had critical stresses in excess of the proportional limit so no correction for this factor was required.

Values of the ultimate stress, theoretical critical stress, and interpreted experimental critical stresses are summarized in tables II-B and C on the basis of average micrometer thickness and average micrometer thickness minus measured pit depths. Donnell's and Southwell's method give approximately the same results with Donnell's being easier to interpret. However, the results by this interpretation are generally higher than the ultimate stress experienced. These methods were devised for analysis of eccentrically loaded columns which do not carry additional load after failure such as a plate may do even though central elements have failed. Even though these methods correlate better with theoretical calculations based on Bleich and Ramsey [2], it is felt that this agreement does not necessarily make them any more correct.

If all plate conditions were exactly as assumed, each plate of a particular series would buckle at the same stress. Interpretation of data by Donnell's and Southwell's methods are misleading. These methods, devised for columns, give an analysis for determining critical load at zero eccentricity. This eccentricity is the major cause of early failure in columns. Using these analyses for wide plates gives poor results, since simple column theory is not strictly applicable. The interaction of several variables affects the data such that an analysis based on eliminating eccentricity alone (assuming negligible effect from the others) is felt to be inadequate and misleading. Since there are several variables to be considered for each series, a simple comparison by the "top-of-the-knee" method is felt to be best suited. Percentage comparison of results by this method based on Bleich and Ramsey's [2] predicted results are listed in Table IV-B.

The intersections of the tangents in the T.O.K. method should have a relationship within a given series. Similar plates with varying eccentricity or initial deflections will behave such that the critical load will decrease as the eccentricity or initial deflection increases. The plot of the intersections should result in a curve which, when extrapolated to the load axis, will give the critical load for zero eccentricity and zero initial deflection. However, correlation by this method was poor except as noted in section IV-C.

B. Variations from Theoretical Conditions

In order to analyse each plate series separately, a summary of possible variations from conditions assumed in theoretical calculations is necessary.

1. Eccentricity of Loading

Eccentricity of loading was not eliminated in these tests but the exact amount present was impossible to measure. The nature of the machine should permit some repeatability of a given eccentricity in a particular series by identical blocking and shimming. The direction of the opposing forces was checked between runs by using a spirit level on the rams and loading bars. No appreciable change in eccentricity was observed beyond occasional loosening of the union of load cell and ram.

2. Initial Plate Curvature

Initial plate curvature has a similar effect as eccentric loading in reducing critical buckling stress. Curvature in the long dimension only would tend to increase critical stress. But curvature in the short dimension will reduce the critical buckling stress by initiating early bending. The first plate tested (40-1/4-1) had no initial curvature and buckled downward. Therefore, any plate with initial curvature was set concave down to counteract the apparent eccentricity and to reduce the initial curvature by sagging. It is felt that, to an extent, initial curvature was used to offset eccentricity.

3. Uniform Distribution of Load

The actual loading on the plates depended on the ram spacing and the stiffness of the hardened steel loading bar. The ram spacing chosen was a compromise between sensitivity of load measuring and sufficient points of load application to the hardened steel loading bar. Since relative stiffness of the bar increased as the "b" dimension of the plates was made shorter, it was felt that little could be gained from moving the rams closer together. (See Figure 1 for ram spacing.) Thus, uniform edge loading was more closely attained for aspect ratios of 1/4

compared to those of 1/2.

4. Edge Rotational Restraint

As concluded previously [5] rotational restraint appears to be negligible. Any restraint would tend to increase the critical buckling stress. The results indicate no such effect and therefore edge rotational restraint is considered as negligible.

5. Planeness of Edges

The condition that all four edges of a plate remain plane is essential to the theoretical development of the plate equation [1]. The short edges were forced to remain plane by the ball bearing raceways. The sharp crease at the plate corners after being buckled in some of the cases is testimony to this fact (see Table XVIII).

Doubt was felt about the "b" edges so measurements of lateral deflections were made at the load cell "b" edge during many of the tests. Results indicate that the milled grooves in the loading bars forced the b-edges to center up and straighten until the final stages of the test. It is believed that the large bending of the plate just before failure results in less lateral restraint from the milled groove of the loading bar at the center of the "b" edges since the loading bar has some stiffness. Therefore, it is concluded that poor shape of the "b" edges of the buckled plates, especially in the small aspect ratios, occurred during the very last part of the tests and did not materially effect the results.

The fact that the load cell "b" edge showed greater distortion can be attributed to inertia in the rams. Hydraulic pressure was applied directly to this set of rams alone. Any load equalization among rams on the parasite side would lag the load application side. It is therefore

concluded that future tests use an equalizing line between manifolds to minimize any possible effect from this cause.

6. Effective Thickness

Plate surfaces varied considerably between series. The 1/4" thickness plates were in the worst shape since pitting and scale was general and severe. Since such pitting and scale must reduce effective thickness somewhat, it was decided to make a gross comparison by considering thickness to the bottom of all pits and compare results with those obtained using micrometer thickness. Since test and theoretical values are related by the cube of the thickness, the true thickness is highly important and will be discussed by individual plate series.

C. Analysis by Plate Series (See Tables II, IV, and XVIII)

1. 40-1/4 (Figures 2, 21)

These plates buckled in a definite plastic hinge, failure occurring with considerable suddenness. Correlation of critical buckling stress determined by the "T-O-K" method with theoretical values on the basis of t is poor. Using t' as a basis, however, permits good correlation of plates #1, 2, and 3. Plate #4 shows early bending indicating eccentricity since the plate had no measurable curvature. An attempt was made to extrapolate to zero eccentricity using the tangent intersections of the T.O.K. curves but the points plotted erratically, making it impossible to obtain a critical stress at zero eccentricity.

Estimates of pit coverage are eye estimates only. Therefore, any attempt to establish a true effective thickness is arbitrary. It is concluded that inaccuracies in determination of thickness is the largest variable in this series. Furthermore, values of critical buckling stress based on t appear to be generally below theoretical predicted values

while use of t' gives better agreement between experimental and theoretical values.

2. 50-1/4 (Figures 8, 21)

This series contains but a single plate; hence there is little value in the result. Thickness considerations do not appear to make much difference. A complete series would be desirable, since the early bending indicates that considerable eccentricity is present. Examination of the curve of average strain at the center of the plate indicates a decrease in strain at high load. This is probably because the loading bar stiffness redistributes the load away from the center as the plate buckles.

3. 50-1/3 (Figures 3, 21)

The plates of this series show the effects of eccentricity and initial curvature quite clearly. There appears to be an interplay of the two effects in plate #1 and more particularly in plate #3 where the plate attempted to buckle in one direction and reversed as the eccentricity forced it to buckle down. Since the initial curvature was up, it may be concluded that whatever eccentricity is present increases with load. This might be caused by elasticity in lateral restraint. This increasing eccentricity tends to counteract initial curvature if the plate is placed concave down. Initial curvature in plates #2 and #4 did not counteract eccentricity and plates behaved as eccentrically loaded. Thickness considerations are also important here since pits are deep and general. It may be concluded that plate #1 seems to balance the effects of eccentricity and initial curvature so that considering a possible reduction in effective thickness, the experimental value of critical buckling stress agrees very well with that obtained by theory.

4. 50-1/2 (Figures 4, 22)

In this series non-uniform distribution of load may be appreciable since the effect of the loading bar stiffness appears on the average strain curves fairly early. This effect is counteracted, however, since bending is sufficient to make stress on one side exceed the proportional limit for plates #2, 3, and 4 long before buckling. Since the real average stress is not then proportional to the average strain, the strain curve bends to the right. This fact plus inspection of the average strain curve indicates that the plastic hinge does not form suddenly in this series as it did in the 40-1/4 series.

Eccentricity, initial curvature, and effective thickness appear to influence the results as in the 50-1/3 series. As before, initial curvature in plate #1 was overcome by eccentricity and the plate buckled down. It appears that the bending in the reverse direction initially weakens the plate so that a plastic hinge buckle more quickly forms when the bending reverses. Again attempts to correlate results by considering the coordinates of tangent intersections is inconclusive. Considering the inaccuracy of the percentage estimate of pits, plate #2 is considered a good corroboration of theoretical buckling stresses.

5. 70-1/4 (Figures 5, 22)

Study of the average strain curves for this series indicates that again the steel loading bar has less effect on the uniform distribution of loads just before failure if the aspect ratio is low. But the unique feature of this series is the absolute uniformity of shallow pits. Thus we are able to evaluate the results considering fewer variables. A simple plot of the intersections of the tangents to the bending curves appears to correlate well, indicating a critical stress slightly above

that of plate #2. Therefore, experimental results confirm theoretical results within a few percent. An exact comparison is not useful since the precise effect of pits is not determinable. These plates appear to have been thoroughly shot blasted and are of extremely uniform thickness which make them unique among the various series tested.

Of further interest is that extreme bending in plate #1 appears to have been caused by initial curvature alone whereas in #3 and 4 eccentricity easily overcame almost the same initial curvature. This would indicate that in this series eccentricity varied considerably among the plates.

6. <u>70-1/3 (Figures 6, 22)</u>

While the surface condition of this series is good, it is not quite as good as the 70-1/4 series. This does not explain the fact that attempts to plot tangent intersections are not very rewarding. However, there is an indication that the critical buckling stress is somewhat higher if there is no eccentricity or curvature. Relatively few readings were taken with plates #1 and #2, and points are scattered in both the bending and average stress curves. Plates #3 and 4 show smooth plots with a particularly smooth plastic hinge development as shown in the average strain plots. It is felt therefore that #3 and 4 may be extrapolated to zero eccentricity and zero initial curvature with some assurance. The result is in agreement within a few percent of predicted values but not as close as with the 70-1/4 series.

7. <u>70-1/2 (Figures 7, 23)</u>

The values obtained from this series are consistently very high compared with theoretical predictions. Thickness is quite uniform and may be ruled out of this case because consideration of pits only increases

the difference. The bending curves are unique in that they show a persistent linear load increase after the "knuckle" until sudden yielding causes a second knuckle. It would appear that the material experiences not only yield but also a sort of ultimate loading. Distribution of loading is non-uniform toward the end of each run for this aspect ratio, but the effects do not appear serious.

The only difference in testing procedure for this series was that a large number of readings were taken at close to failure loads. Holding the load steady for a longer interval may have permitted adjustment of the loading throughout the plate so that bending was not localized.

Fortunately, plates #2 and 4 have little apparent eccentricity. Inspection of their bending curves shows that disregarding the second knuckle will give the following results based on t.

	P_{cr} (kips)	σ_{cr} (exp) (Ksi)	σ_{cr} (theor.) (Ksi)
70-1/2-2	28.0	8.33	8.66
70-1/2-4	28.6	8.48	8.66

The results are therefore good and seem to bear out a conclusion that slow application of load will give better results. It should be borne in mind that these particular plates show an unusual lack of eccentricity permitting the isolation of this added variable.

D. Accuracy of Load Measurements

The method used for measuring load employed three load cells in electrical series, sampling the load from each of three rams and averaging the result. The load cells were calibrated in a 300,000 pound test machine against a gage accurate to 750 pounds. Since the three load cells were subjected to 95,000 pounds total load, a possible error of 3/4% is predicated. Good repeatability of the calibration data indicates

that the load cell measuring system is consistent within the accuracy of the 300,000 test machine. Creep gives some loss in accuracy, but careful cycling minimizes this effect, keeping the total error within two percent at high loads (see Appendix F).

Of pressing interest is what happens when three load cells sample the friction variations from five and seven rams. Table VIII gives some idea that load variations among rams may be as much as 7 percent. Of course, the presumption that each load cell is identical in reaction to a given load is necessary for this evaluation. Pittman and Rinehart [5], under more carefully controlled conditions, estimated an average friction force of 5% of applied load. According to Table VIII, the three center rams have approximately average friction. Therefore, use of these three load cells to sample the load will give a representative value of the load applied by the five or seven ram combinations. It is estimated that the error may be as much as three to five percent under these conditions. However, this error can be reduced by recalibrating the machine since the three load cells may be accurately checked with five and seven ram combinations.

Of course, it is assumed that lapse of time has not changed calibration conditions. There would be little worry about this factor if it were not for the unexplained failure of the seven load cell circuit to perform as expected (Appendix F). A recalibration should be performed either before further testing or after completing the tests of the remaining plate series.

It is concluded that a total error of one to six percent of total load is possible with error increasing with the number of rams and the total loading on a given set of rams.

E. Recapitulation of Error

The results of these tests indicate that errors arise chiefly from eccentricity, plate initial curvature, errors of load measurement, speed of load application, and measurement of effective thickness. Further error may result from improper determination of the modulus of elasticity (appendix F). The exact interplay of these factors need precise attention in future work.

FIGURE 2
LOAD vs STRAIN-DIFFERENCE
σ_{CR} DETERMINED BY TOP-OF-THE-KNEE METHOD

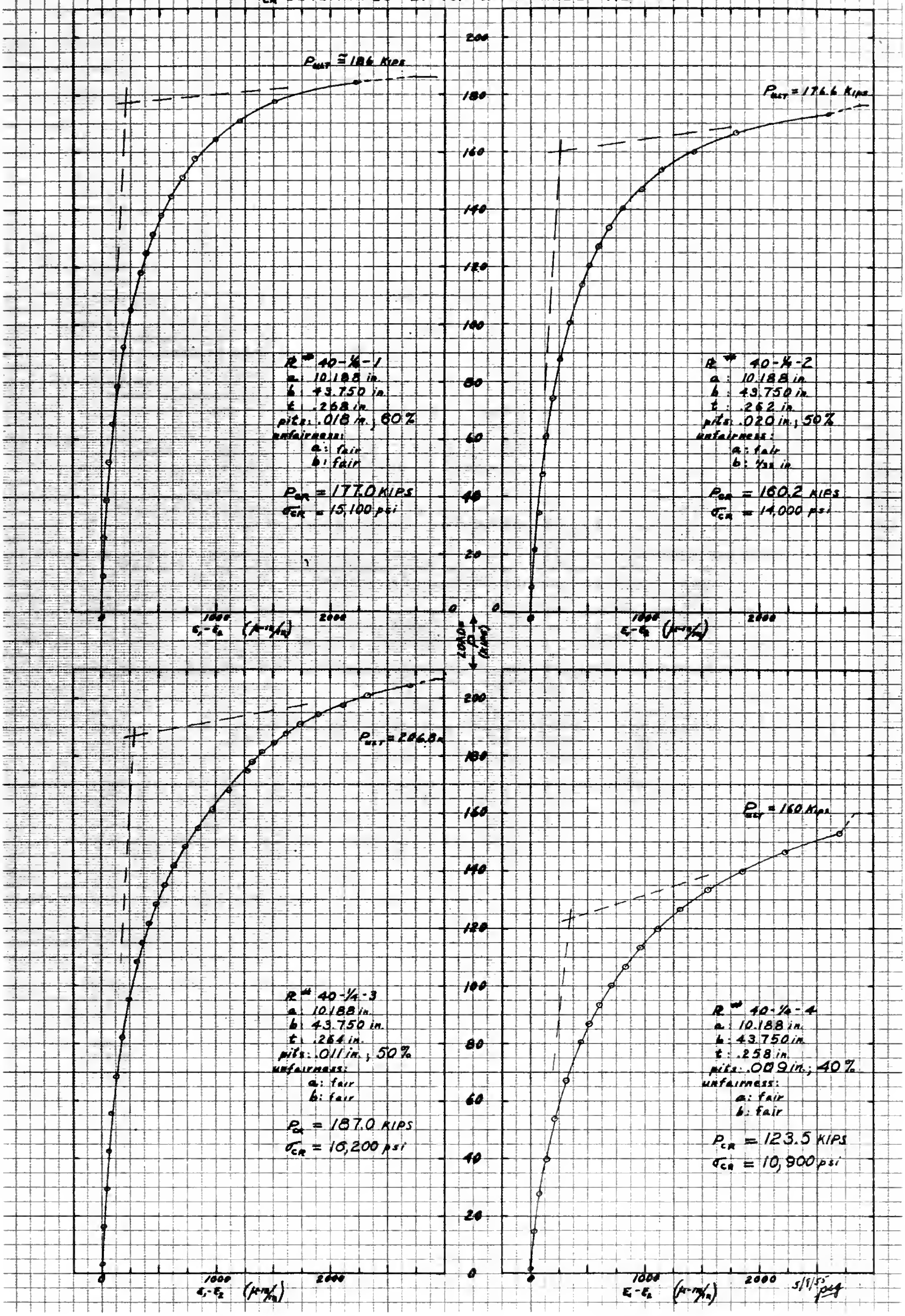


FIGURE 3
LOAD vs STRAIN-DIFFERENCE
σ_{cr} DETERMINED BY TOP-OF-THE KNEE METHOD

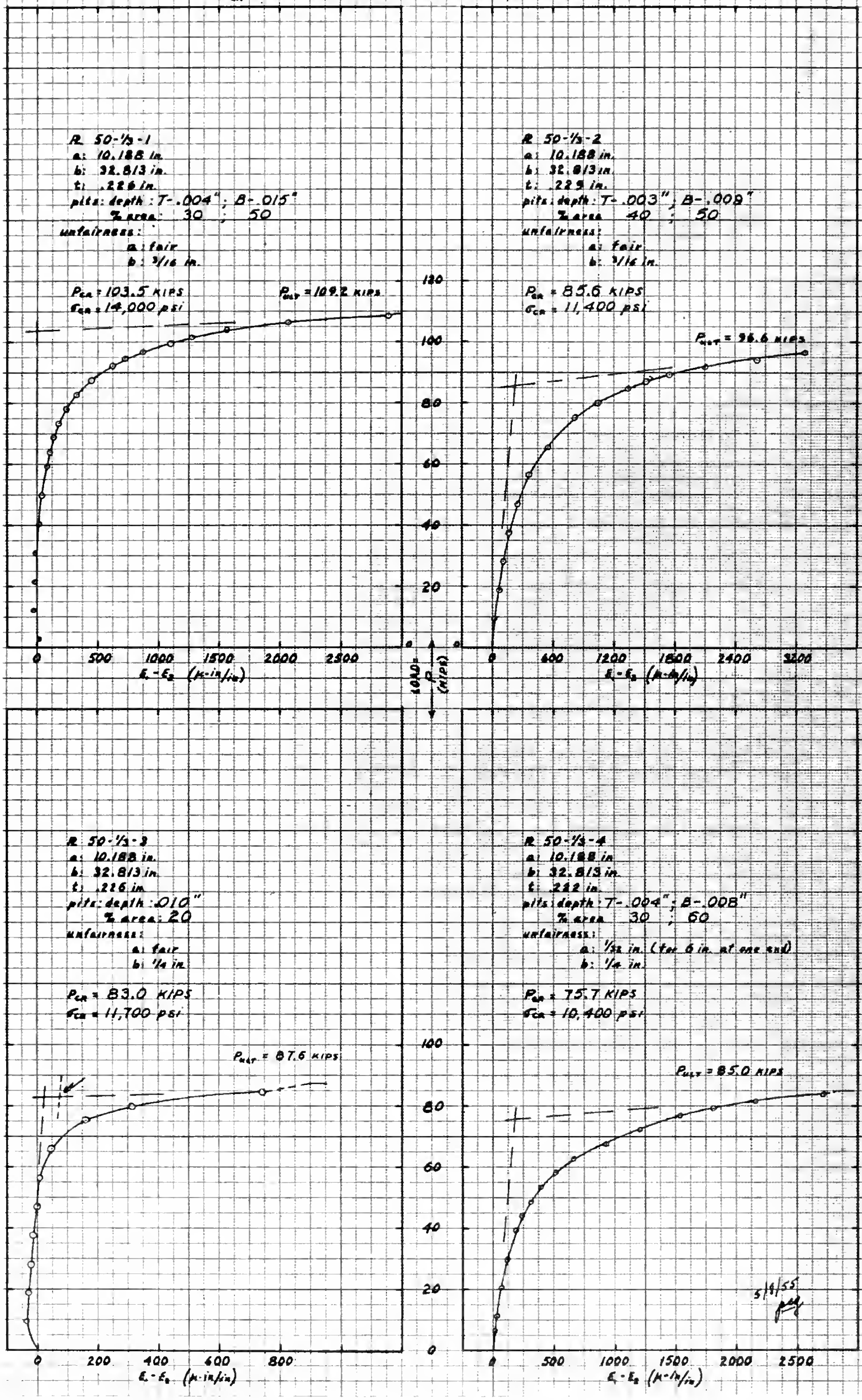


FIGURE 4

LOAD vs STRAIN-DIFFERENCE

σ_{cr} DETERMINED BY TOP-OF-THE KNEE METHOD

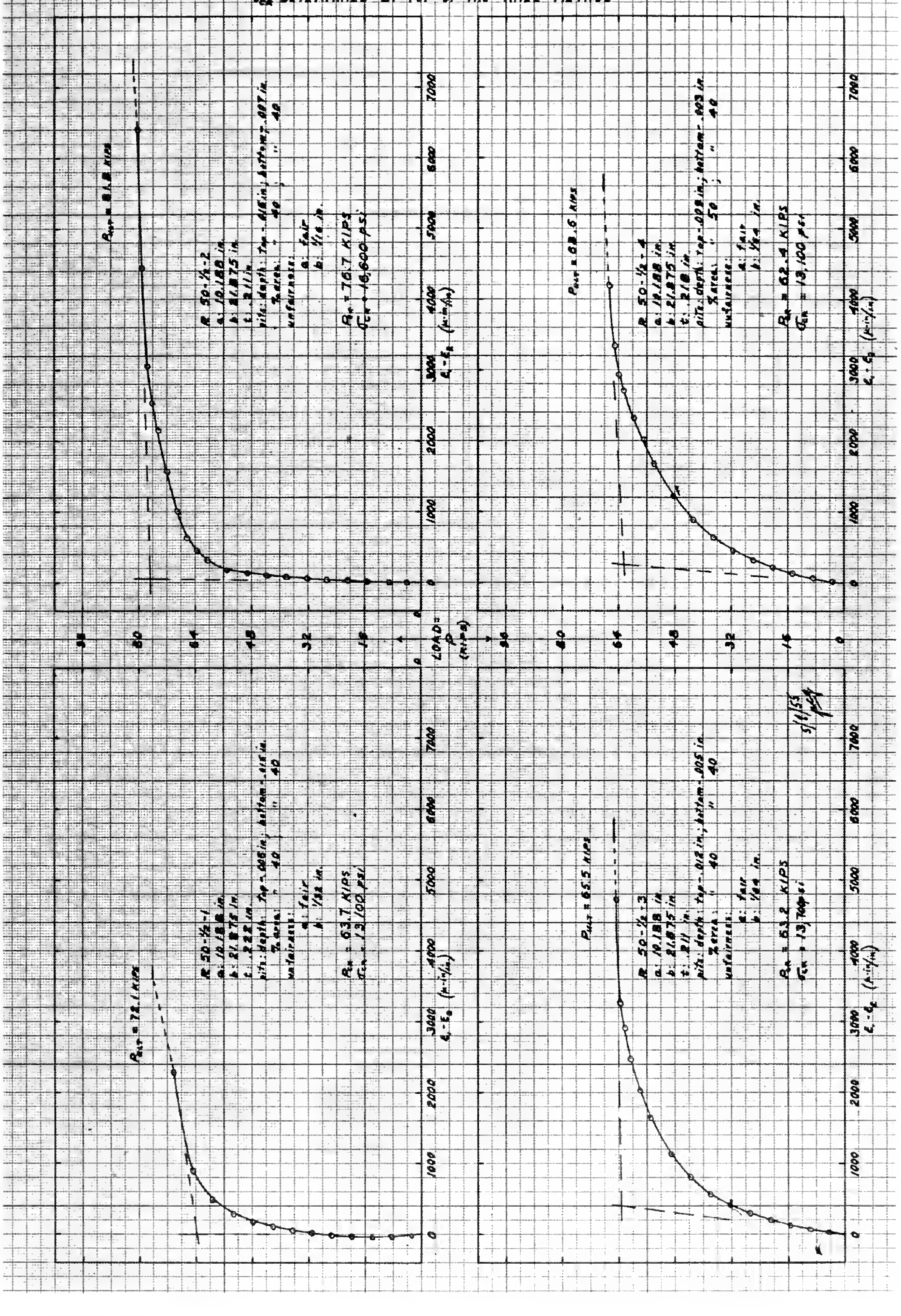


FIGURE 5
LOAD vs STRAIN-DIFFERENCE
σ_{CR} DETERMINED BY TOP-OF-THE-KNEE METHOD

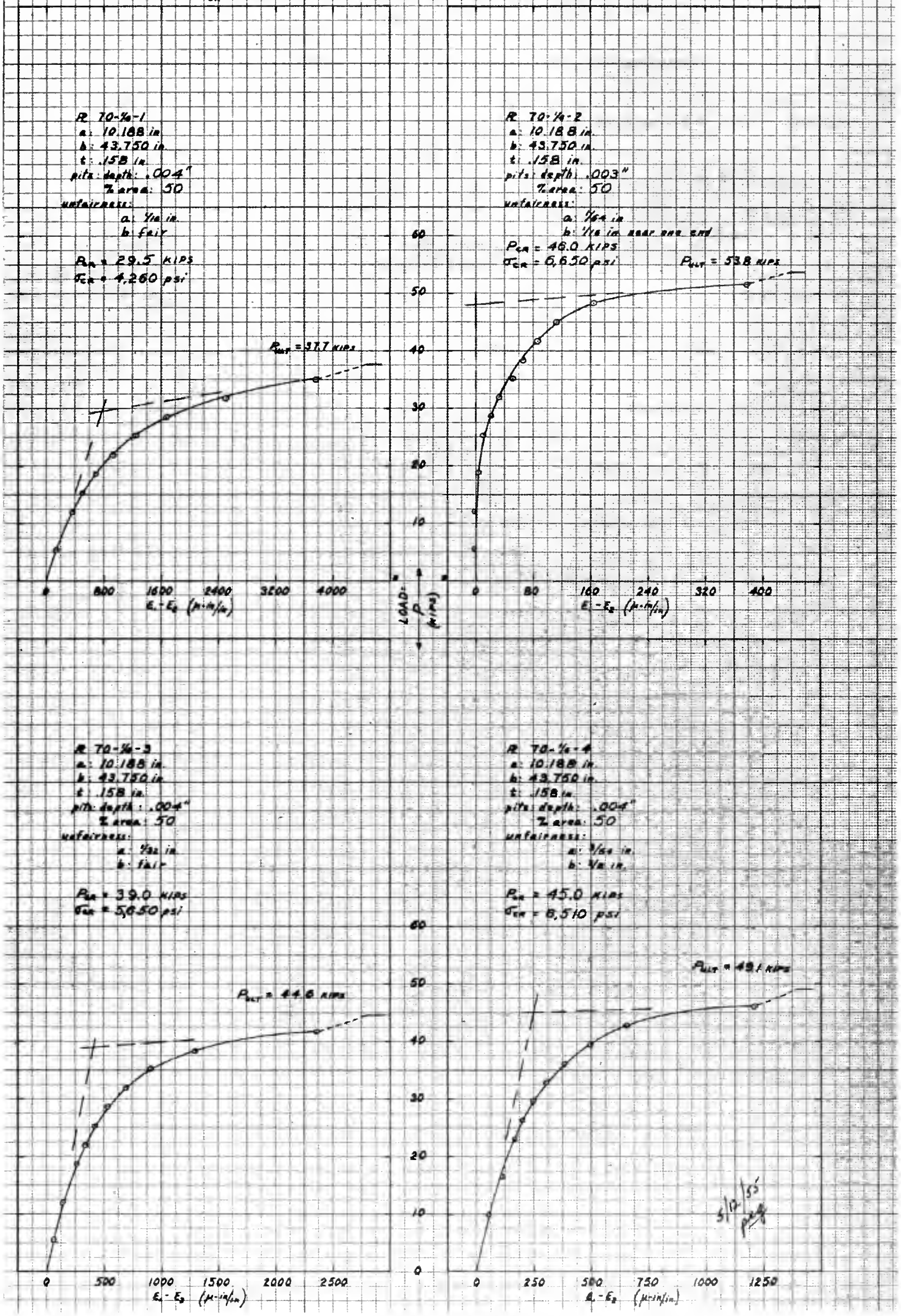


FIGURE 6
LOAD vs STRAIN-DIFFERENCE
σ_{cr} DETERMINED BY TOP-OF-THE KNEE METHOD

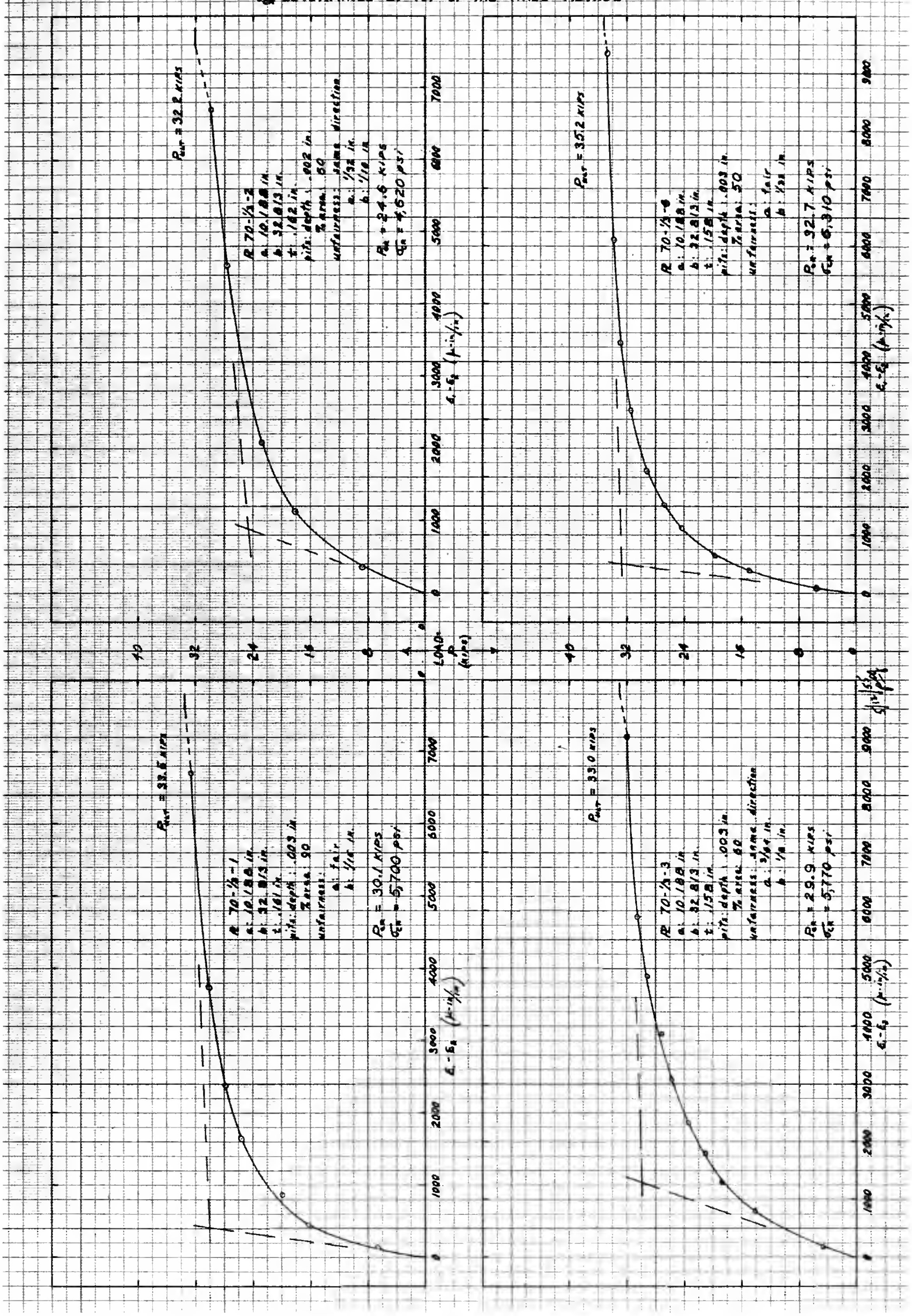
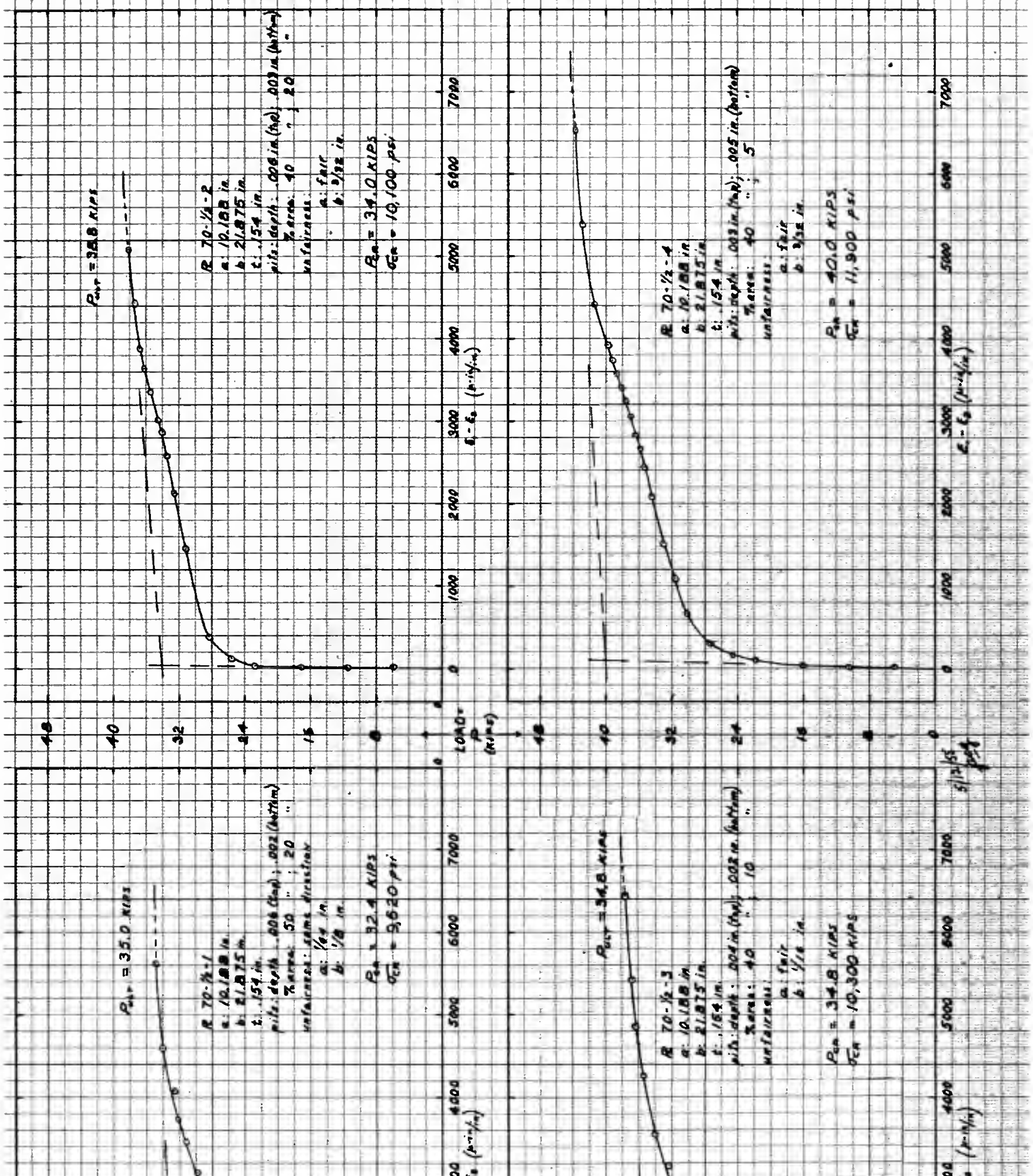


FIGURE 7

LOAD vs STRAIN-DIFFERENCE

σ_{cr} DETERMINED BY TOP-OF-THE KNEE METHOD



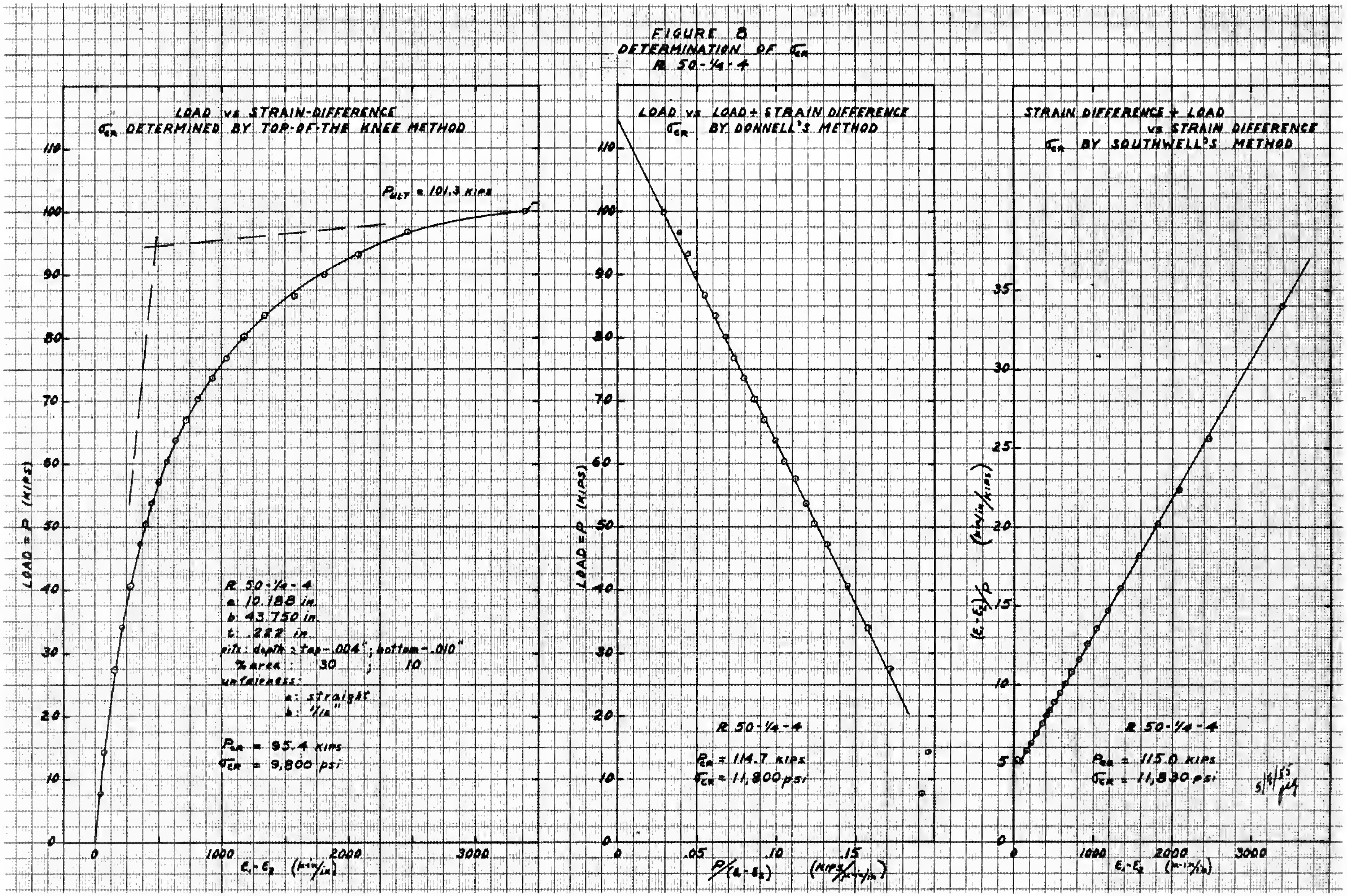


FIGURE 8
DETERMINATION OF σ_{CR}
R 50-1/4-4

FIGURE 9

LOAD vs LOAD ÷ STRAIN DIFFERENCE

σ_{CR} BY DONNELL'S METHOD

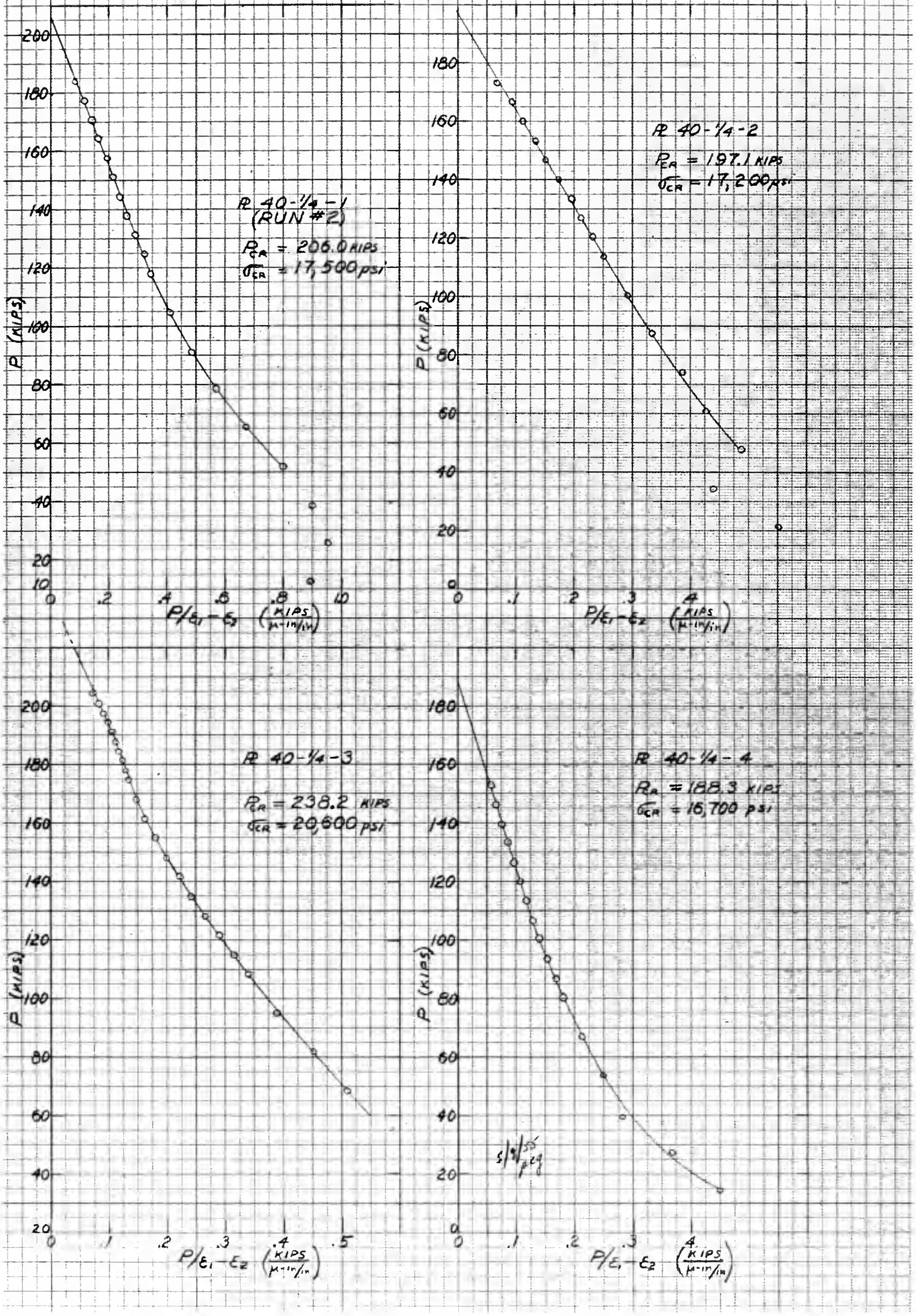


FIGURE 10

LOAD vs LOAD ÷ STRAIN DIFFERENCE

σ_{CR} BY DONNELL'S METHOD

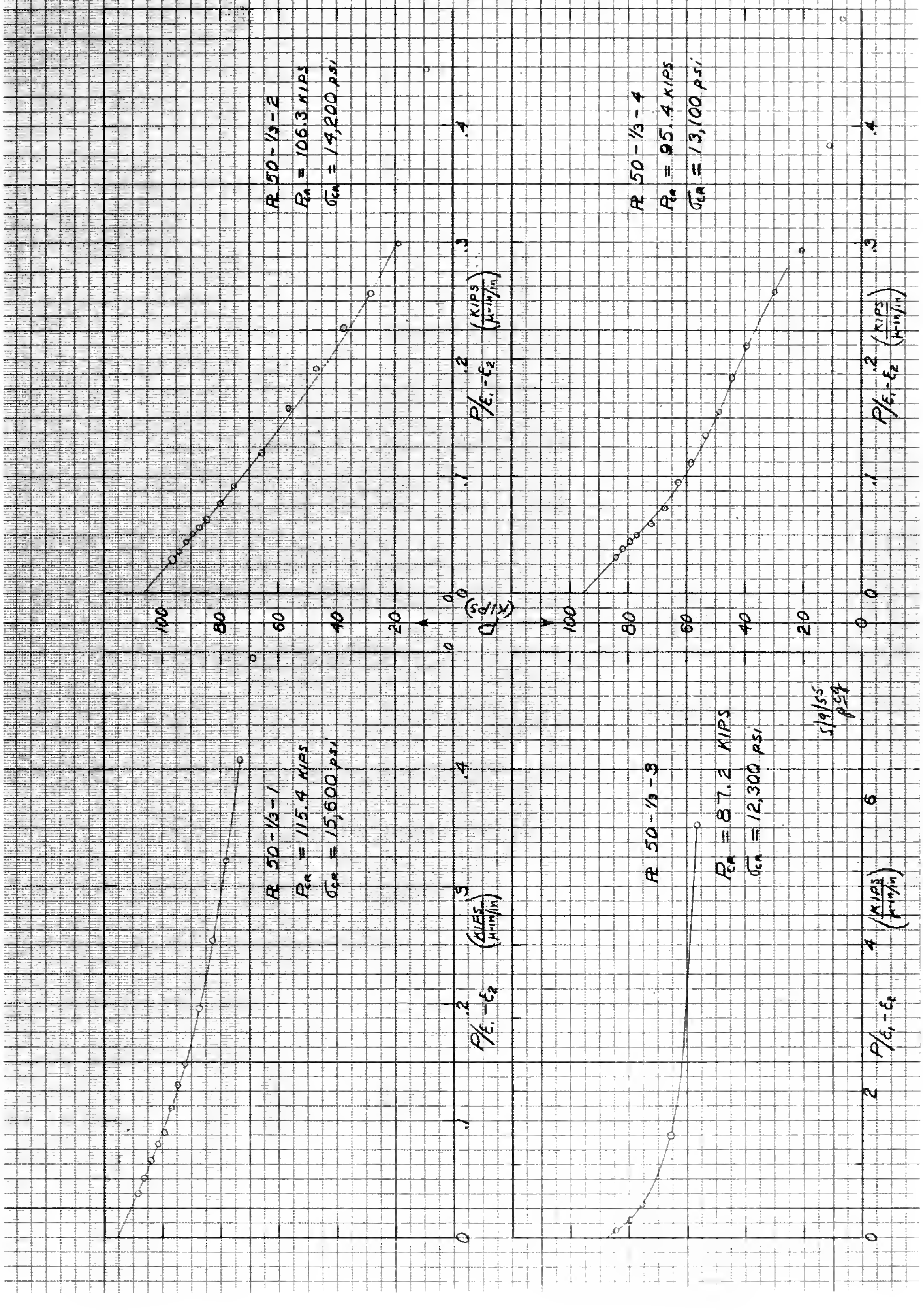


FIGURE 11
LOAD vs LOAD ÷ STRAIN DIFFERENCE
σ_{CR} BY DONNELL'S METHOD

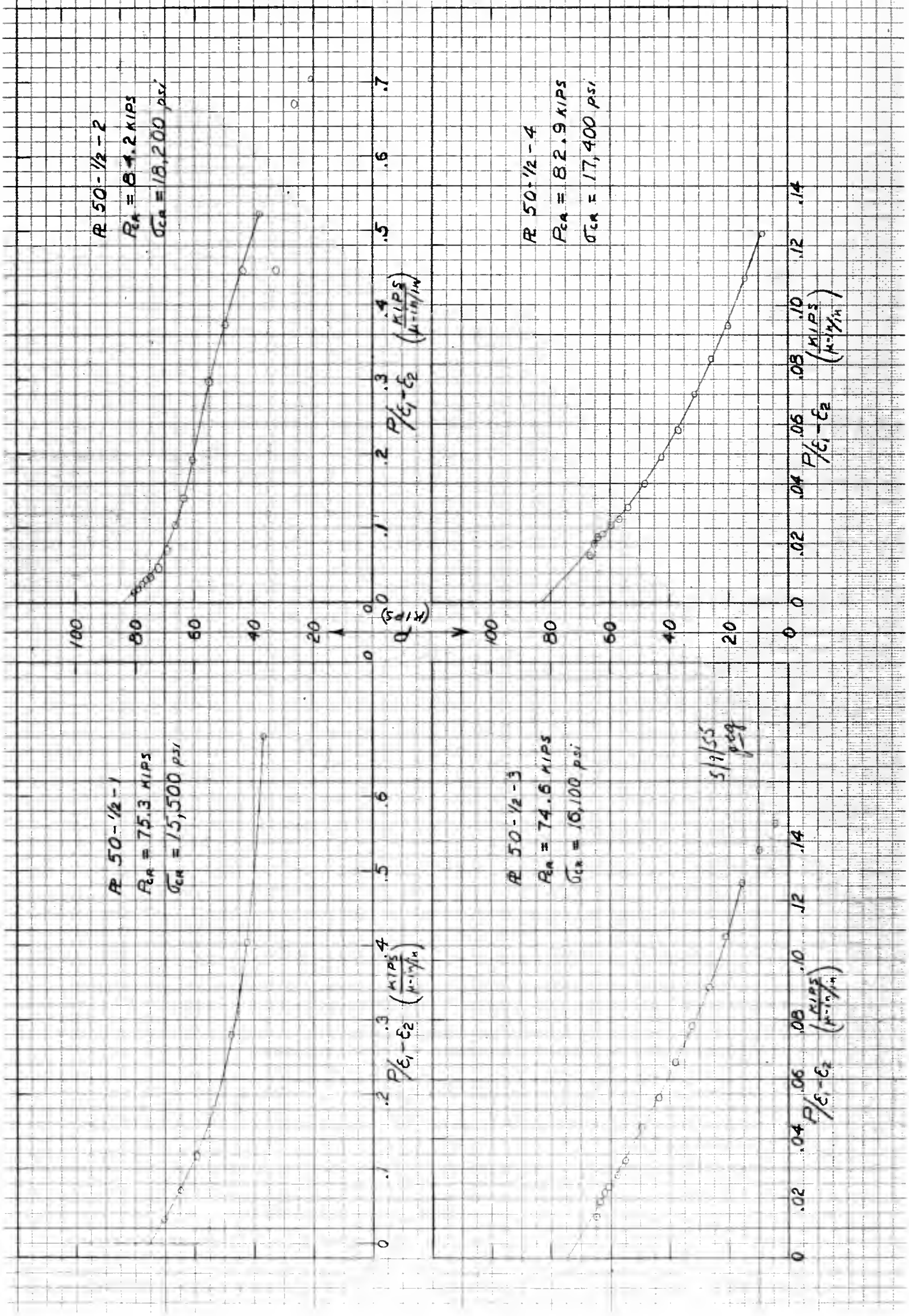


FIGURE 12
LOAD vs LOAD ÷ STRAIN DIFFERENCE
σ_{CR} BY DONNELL'S METHOD

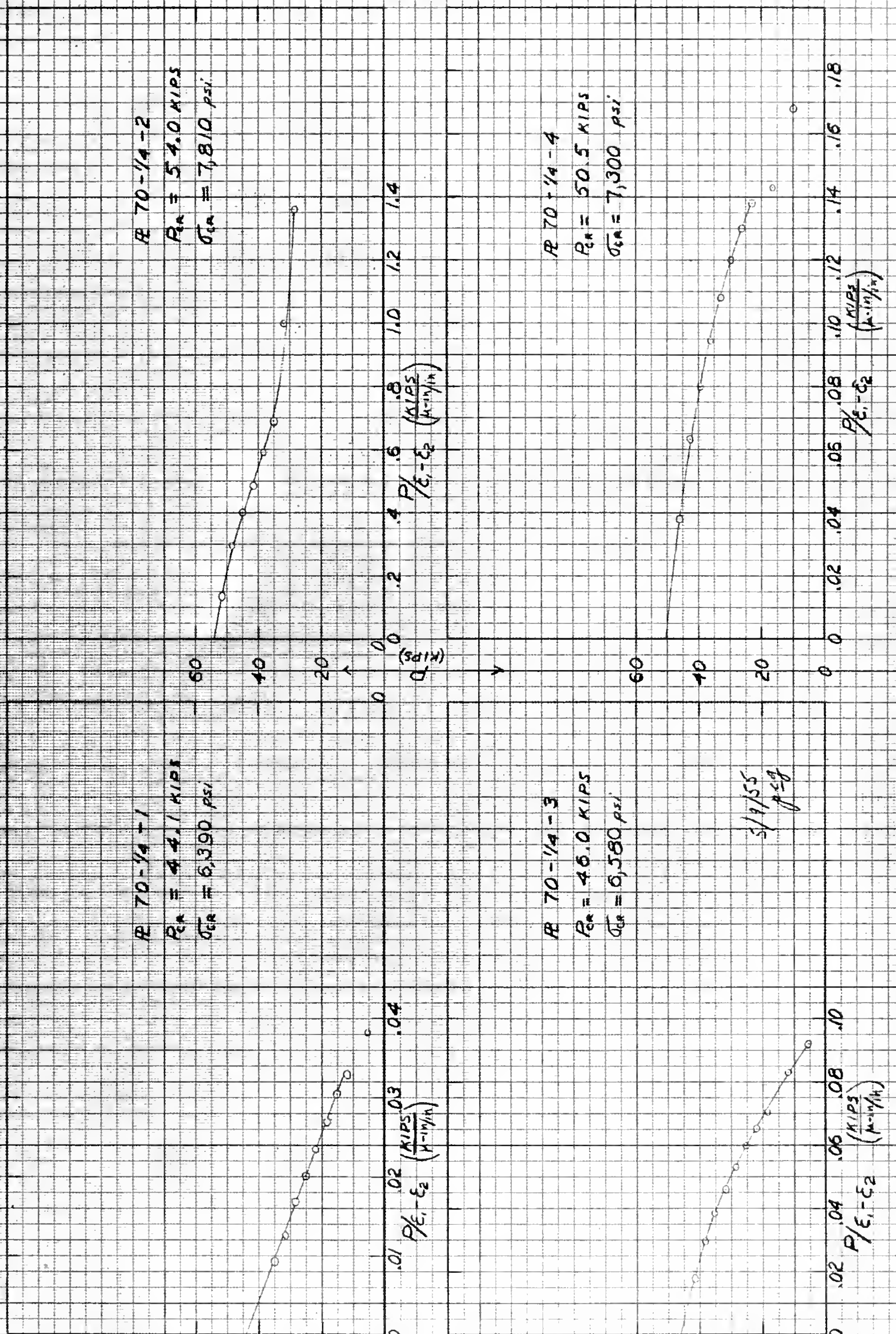


FIGURE 13
LOAD vs LOAD ÷ STRAIN DIFFERENCE
σ_{CR} BY DONNELL'S METHOD

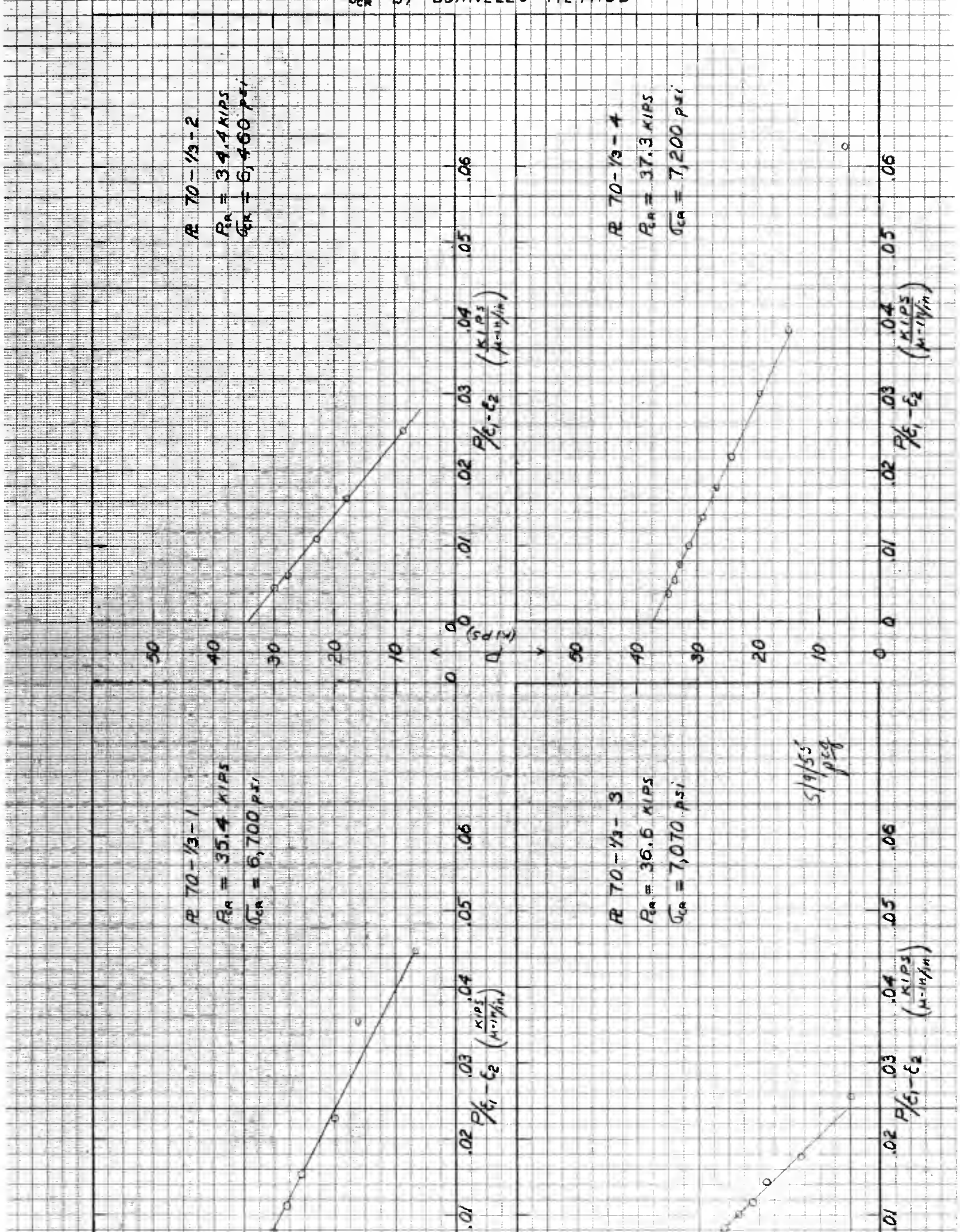


FIGURE 14

LOAD vs LOAD ÷ STRAIN DIFFERENCE

σ_{CR} BY DONNELL'S METHOD

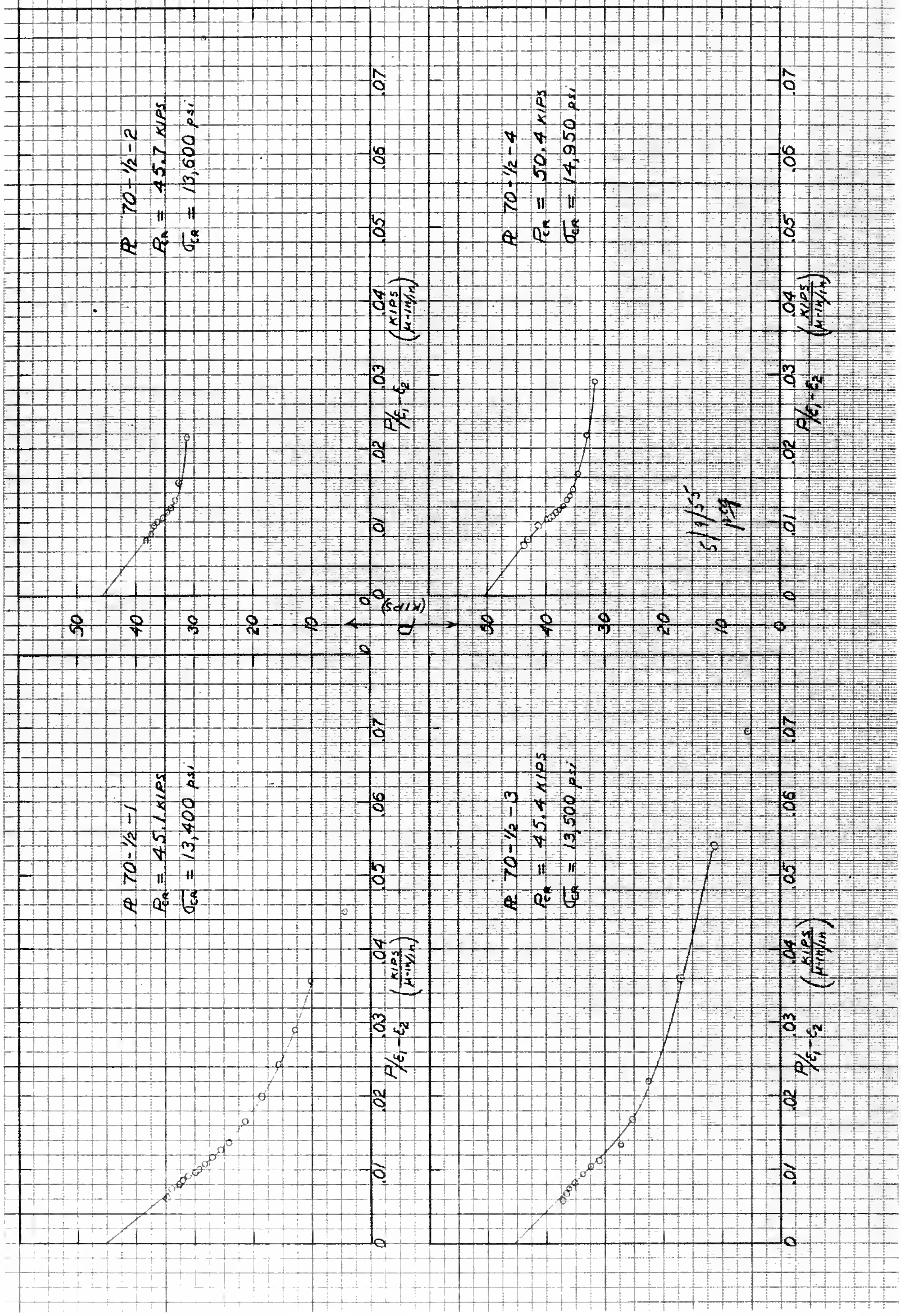


FIGURE 15
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{cr} BY SOUTHWELL'S METHOD

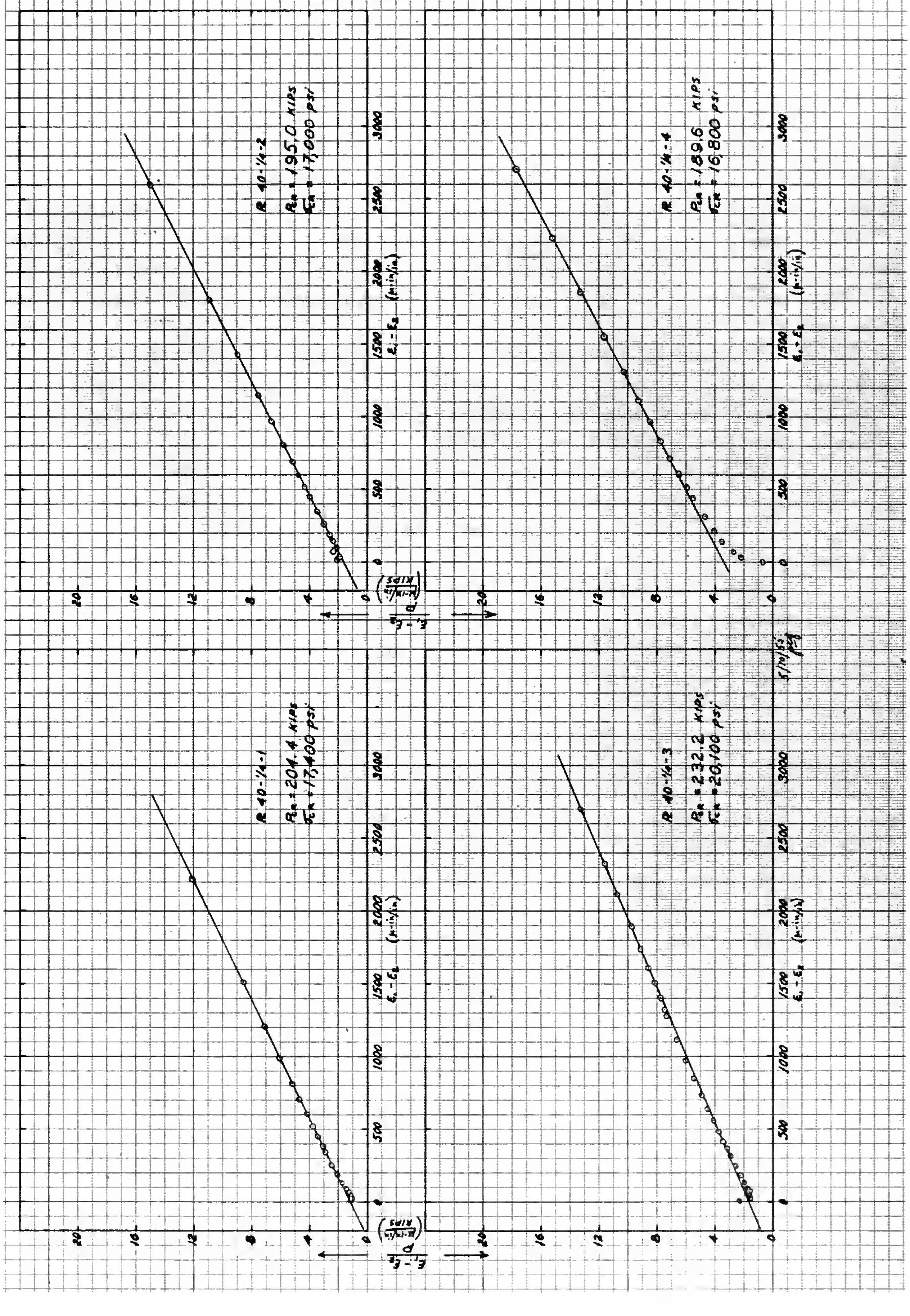


FIGURE 16
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{cr} BY SOUTHWELL'S METHOD

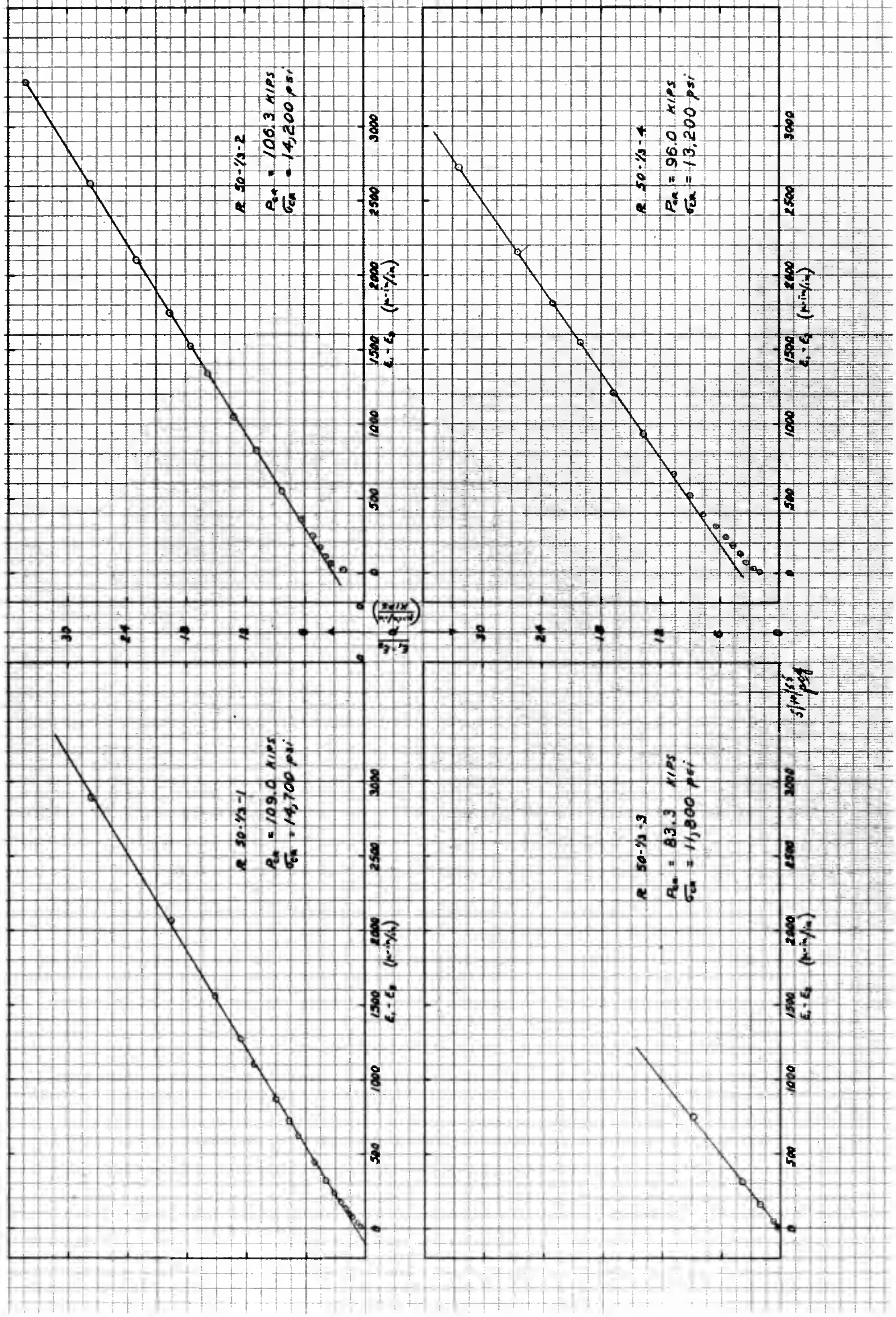


FIGURE 17
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{CR} BY SOUTHWELL'S METHOD

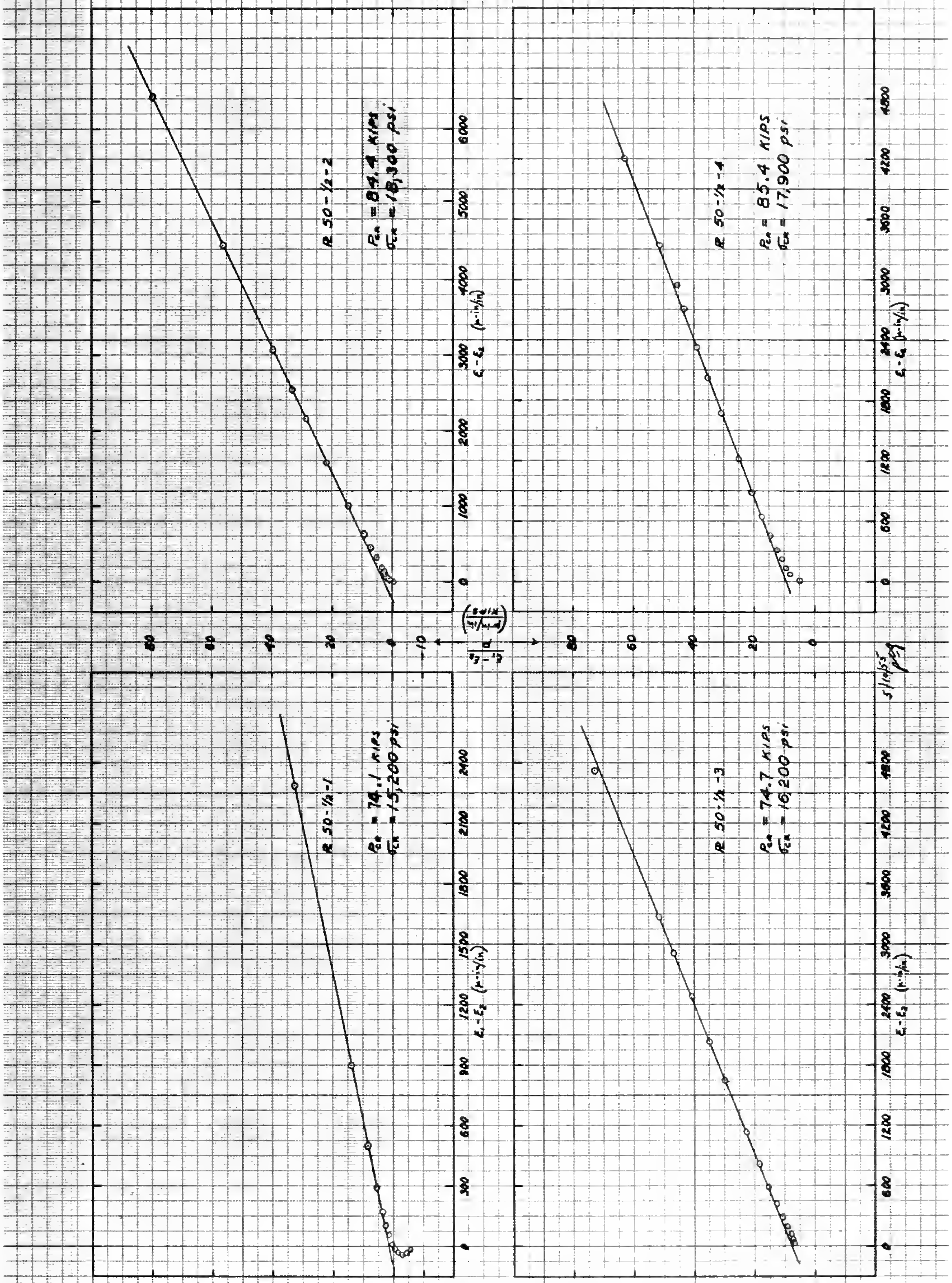


FIGURE 18
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{cr} BY SOUTHWELL'S METHOD

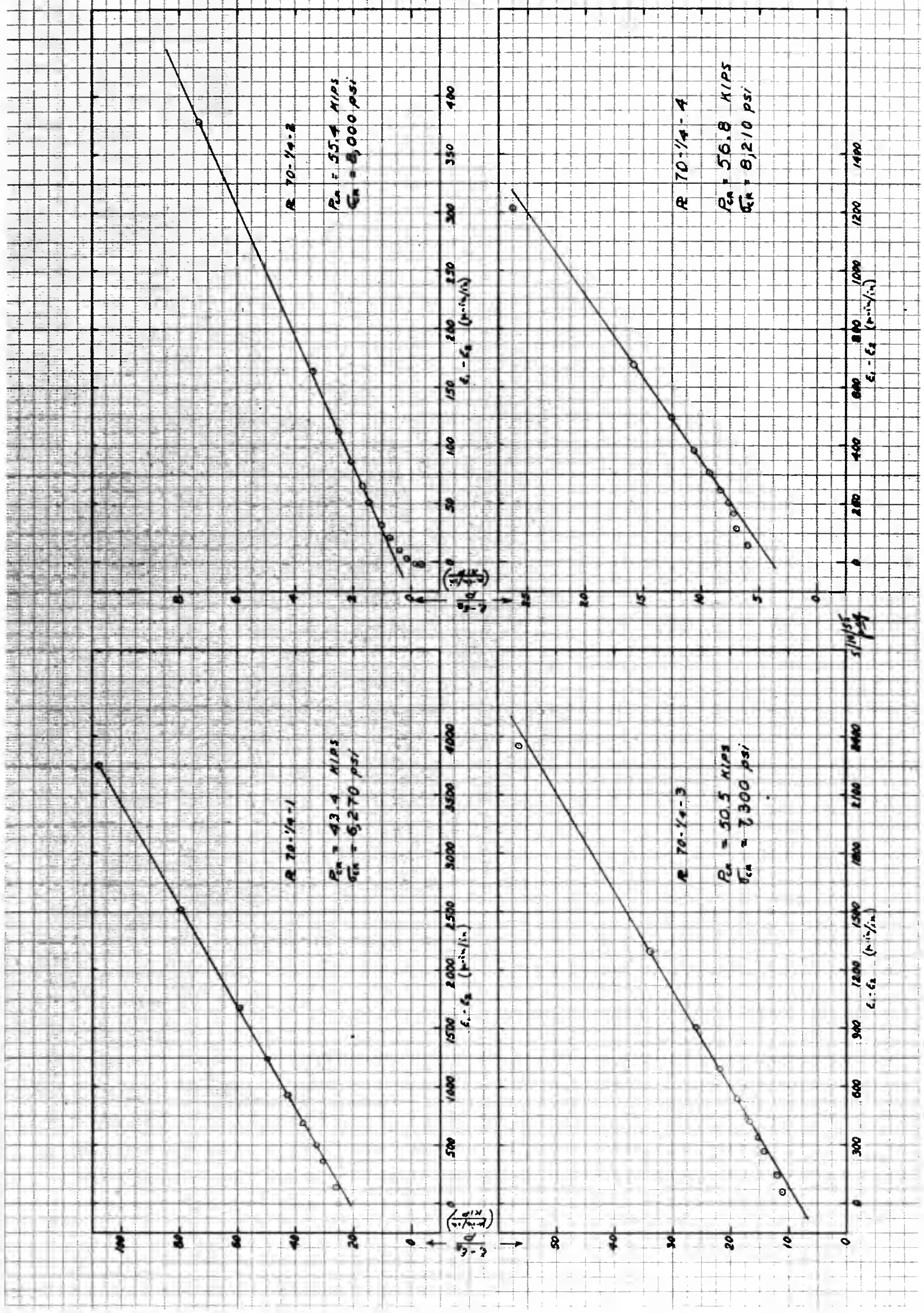


FIGURE 19
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{CR} BY SOUTHWELL'S METHOD

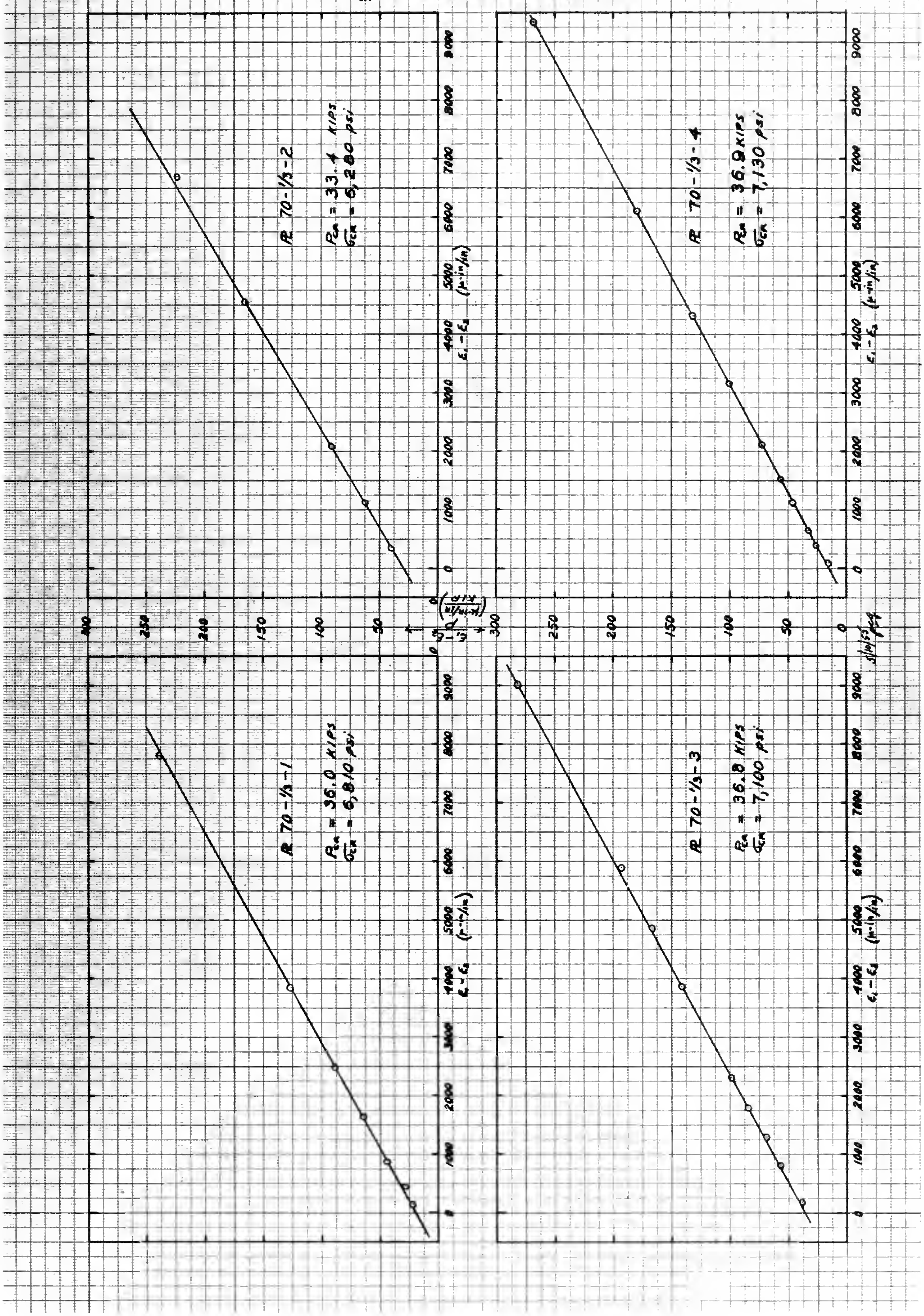


FIGURE 20
STRAIN DIFFERENCE ÷ LOAD vs STRAIN DIFFERENCE
σ_{CR} BY SOUTHWELL'S METHOD

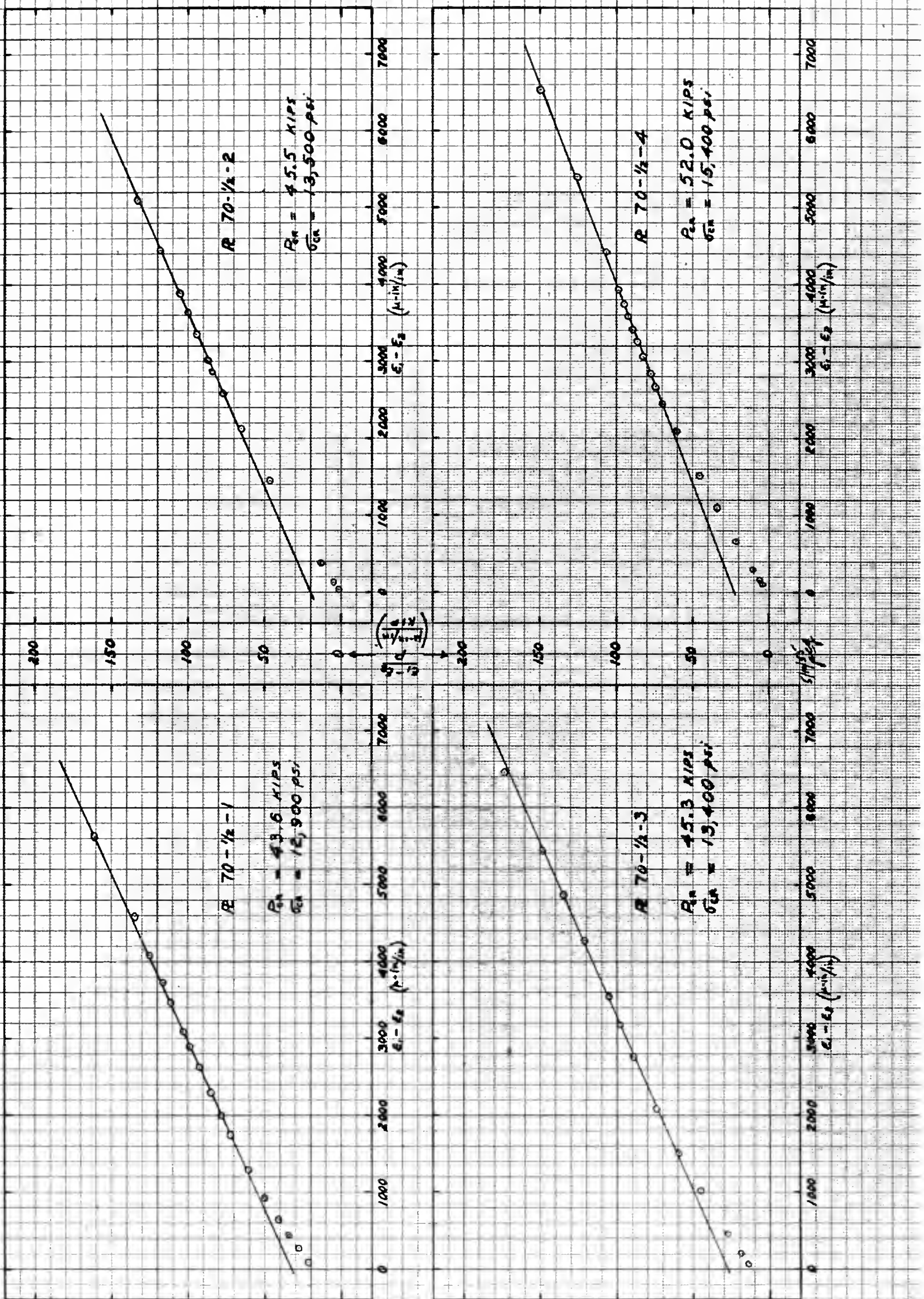


FIGURE 21

LOAD vs AVERAGE STRAIN

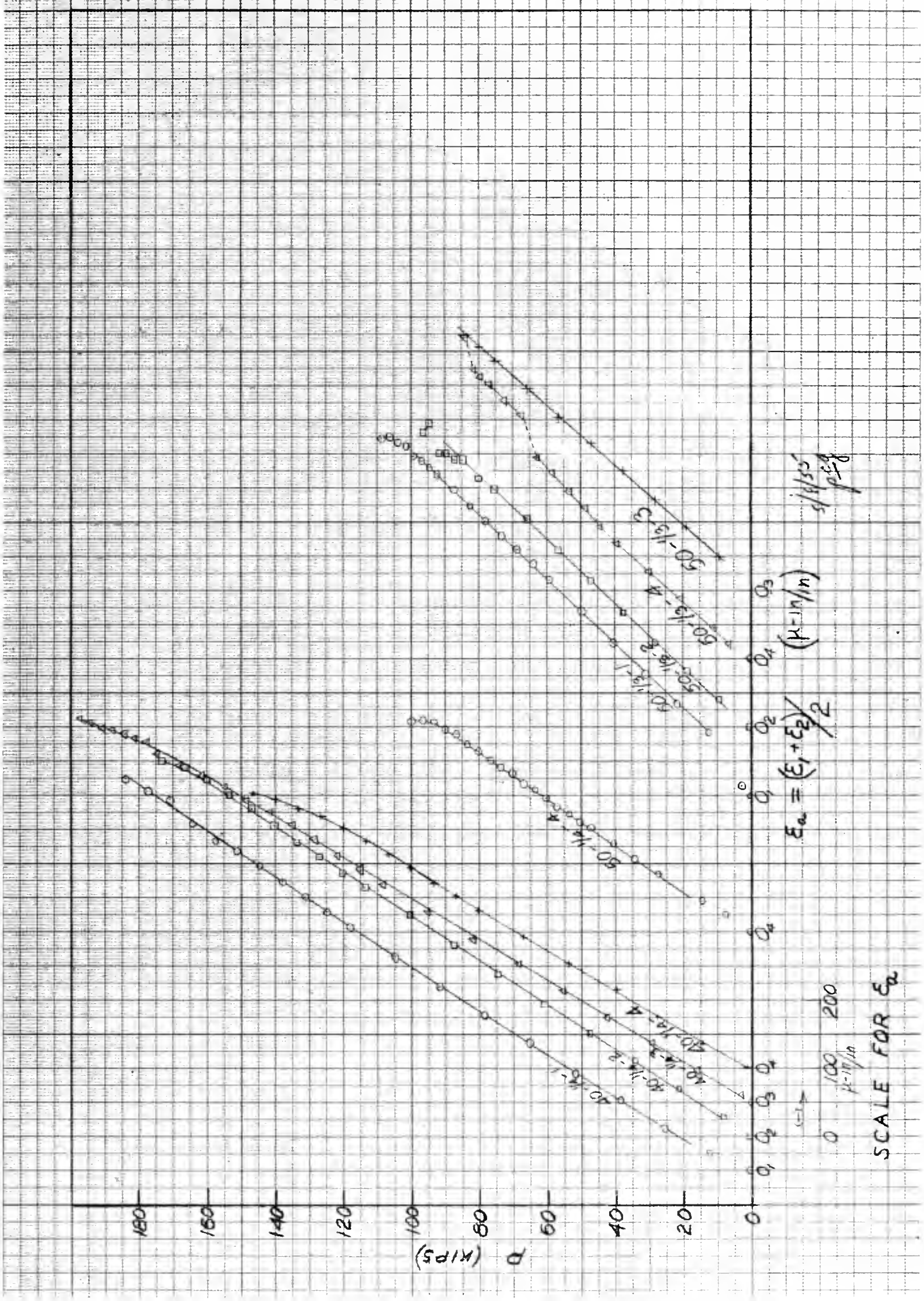


FIGURE 22

LOAD vs AVERAGE STRAIN

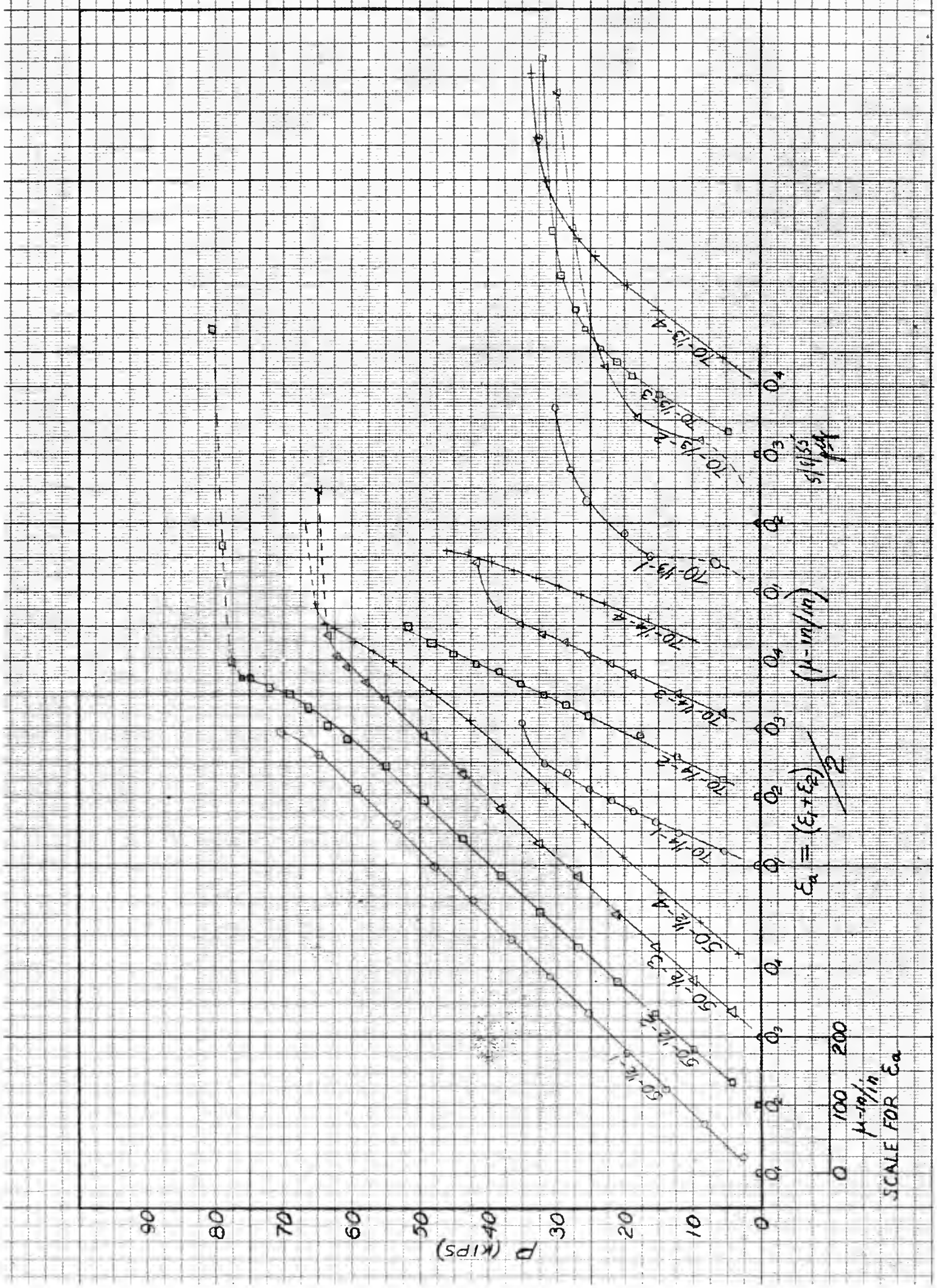
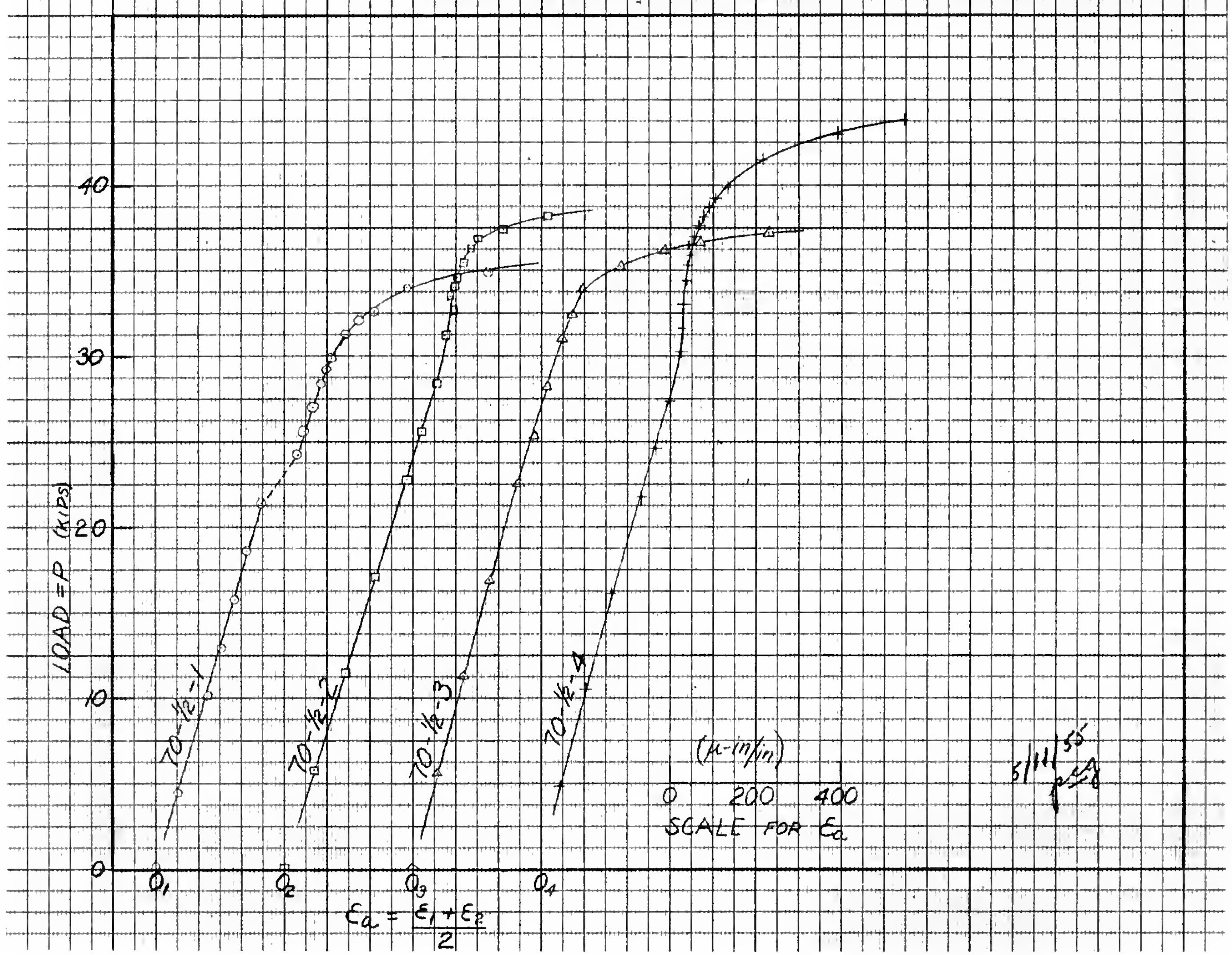


FIGURE 23

LOAD vs AVERAGE STRAIN



V. CONCLUSIONS

1. Interpretation of data is difficult because several variables of indefinite effect are present.

2. The Top-of-the-Knee method of data analysis seems to be the most realistic.

3. The actual effective thickness of the plate is critically important for both experimental and theoretical considerations. This effective thickness appears to be somewhere between t and t'.

4. The test frame, loading arrangement, and measuring system functioned satisfactorily.

5. Eccentricity and initial plate curvature interact to affect the results obtained, but this method of testing does not allow a precise segregation of these factors.

6. Uniformity of loading need only be approximated since this has only a minor effect on the results.

7. Edge conditions do approach simple support.

8. Edges remain in a plane until the last stages of the test when yielding of the plate reduces the lateral restraint provided by milled groove of the loading bar.

9. Best results are obtained with a series of plates which have uniform thickness with uniform, shallow pits.

10. Rate of applying the load affects the data. Small incremental increases of the load in the critical range results in a "double-knee" curve with the lower knee defining a critical stress that correlates very well with Bleich's predicted value.

11. The final buckled shape can be expected to be a plastic hinge for plates having a/b and a/t ratios similar to the plates tested.

12. Error of load measurement is estimated to range from one to six percent, increasing with total load and number of rams used to apply the load.

13. The major causes of experimental error are (1) eccentricity, (2) initial plate curvature, (3) load measuring instrumentation, (4) speed of load application and (5) the measurement of effective thickness.

14. The results show fair agreement with Bleich's predictions.

15. There does not seem to be any scale effect except that, in large panels, pit depths will be of the same order of magnitude as in the test panels. Thus the reduction from overall thickness to effective thickness will be less, percentage wise, for full scale panels.

VI. RECOMMENDATIONS

1. Recalibration is strongly recommended using the three center load cells as electrically active when three, five, or seven rams are applying the load.

2. Remaining plates should be shot blasted before being tested to reduce pit variations.

3. The test machine must be cycled immediately before conducting a test.

4. Ram alignment should be checked between test runs.

5. While testing a given series, required shimming should be placed in the same location for the different plates to reduce eccentricity variations.

6. Plates should be inserted concave down into the test rig to reduce initial curvature.

7. Use the pressure gage to estimate the load when cycling. Do not use it as a load measurement during testing except as a rough check against overloading the test frame.

8. The Top-of-the-Knee method is recommended for analysing the data.

9. Use the plot of load versus average strain to check the functioning of the test apparatus. If bending is not severe at the start of a test run, this plot should show a linear relation between P and ε_a.

10. The modulus of elasticity for the 5/32" steel should be checked before further analysing plates of this thickness.

11. A separate study is required to determine effective thickness. A relationship correlating measured overall thickness, pit depth and

coverage, to the effective thickness is not available at present.

12. The load measuring system can be improved considerably if the expense can be justified. New load cells made from special high yield steel (σ_y = 150,000 psi) will probably eliminate the creep phenomenon experienced in the present load cells of CRS steel. This would eliminate the need for cycling the test machine, which means a great saving of time.

VII. APPENDIX

A. SUPPLEMENTARY INTRODUCTION

After the completion of the work of Pittman and Rinehart, it was contemplated that further simply-supported plate buckling tests would proceed without difficulty. To this end Gaucher and Rinehart attempted to continue the program during June, 1954, with completion anticipated by the present authors. However, it was found that lateral restraint of the ball bearing races could not be maintained under higher loads. Specifically, the arrangement of angles and rods which provided lateral restraint failed at approximately 90,000 lbs. load during the test of a plate. This difficulty terminated plate testing by Gaucher and Rinehart.

The authors attempted to eliminate the problem by designing a new lateral restraining system. Since it was calculated that the previous system had failed at approximately 6,000 pounds per rod, the authors felt that the new system should be designed to at least double this load, based on the assumption that the lateral load was caused by eccentricity and would therefore vary linearly with the applied load. The new design eliminated the turn-buckles, replaced the angles with 8" x 8" wide-flange I-beams, and replaced the 3/8" rods with 1/2" rods terminated in welded loops and eye-bolts. Lateral adjustment was made through use of lock nuts on the eye-bolts (see Fig. 24).

One of the 50-1/4 plates was placed in the modified apparatus in accordance with the procedure outlined by Pittman and Rinehart [5]. As the load was applied, it was necessary to tighten diagonally opposite lateral supports, indicating a rotative couple. When the load reached 60,000 pounds, it was noted that the upper head of the machine had moved laterally approximately two inches, relatively independent of the restrained plate. The test was terminated at this point because of the

Figure 24

Original Test Apparatus

Original test apparatus showing modification consisting of heavy tie-rods and eye bolts connected to reinforced 8" wide flange I-beam.

Figure 25

Ruined Test Plate

Test Plate in original test rig after removal of load that resulted in twisted b edge. (Note curved line of segments)

obvious eccentricity induced. It was then noted that the hardened steel bar with its milled concavity had forced the upper edge of the plate to curl over (Fig. 25).

The results of this test indicated that not only did the ball bearing races need further restraint, but also the upper head of the 300,000 pound testing machine as well. The movement of the upper head appeared to result from the long unsupported lengths of four inch threaded shafting upon which the upper head traveled. The fact that the test apparatus, for practical purposes, consisted of a long relatively slender column with elastically supported ends broken by two pin joints (the two segmented edges of the test plate) meant that the problem was considerably more difficult than at first contemplated. The importance of the double pin joints was further demonstrated when calibration runs were later carried out up to 220,000 pounds without difficulty. The calibration set-up consisted of a single pin joint, one set of jacks, and no lateral restraint whatsoever.

Lateral restraint for the upper head proved impractical in the following ways. The existing test machine frame was insufficiently strong at the height required and would have required a complex supporting truss. The problem of attaching lateral restraint to the upper head would have been difficult without altering the 300,000 pound test machine itself. The complexity of any designed arrangement would have rendered its use impractical in view of the intense and varied testing programs carried out on the 300,000 pound testing machine. There was a further question as to the load to which the lateral restraint would have to be designed since it was not known precisely what proportion of the lack of stiffness of the upper head could be blamed on eccentricity or instability.

For these reasons it was felt that a new machine which could be devoted to plate buckling projects should be designed.

B. DETAILS OF PROCEDURE

1. Design of New Test Apparatus

a) General

The impossibility of providing sufficient lateral restraint for the testing jig of Pittman and Rinehart in the 300,000 pound testing machine indicated that some form of radical departure from the existing set-up was necessary. Recently there had been a new test bed built in the Ship Structures Laboratory located in Building 41. This bed is composed of a gridwork of I-beams imbedded in concrete. The twenty ton Blackhawk rams used by Pittman and Rinehart for load distribution were also available for load applications. The design problem presented can be divided into three parts. It was necessary to design a simple hydraulic system with sufficient capacity to supply seven twenty-ton rams and yet retain fine control at all loads. Further, a test framework was required to maintain both lateral restraint for the test plates, and support for the 18" I-beam heads under loads of up to 280,000 pounds. The most difficult part of the problem was the design of a system for measuring loads with an accuracy approaching American Society for Testing Materials standards for a range of loads of 25,000 pounds to 280,000 pounds.

b) Hydraulic load application and control.

At first, the authors felt that hydraulic loads would have to be applied from both sides of the test plate in order to insure maximum flexibility in the use of the machine. However, variations in the strength of the ram retraction springs meant that there would be considerable difficulty in maintaining alignment. Therefore, the rams on one side of the test plate were not directly connected to the hydraulic pump. These jacks were therefore left connected to a common manifold in

order to provide load distribution as described by Pittman and Rinehart [5].

Consultation with representatives of the Blackhawk Manufacturing Company elicited the information that the P-182 high-pressure electrically driven hydraulic pump would provide 5,000 psi. continuous pressure and 10,000 psi. intermittent pressure at a volumetric capacity of approximately 26 cubic inches per minute (see Fig. 26 for pump data). The pump oil tank provided a further limit because it held only enough oil for full travel of five rams. An additional oil supply, at the same level as the pump, was provided by the authors using a large rectangular shallow tank shown in Figs. 26 and 37.

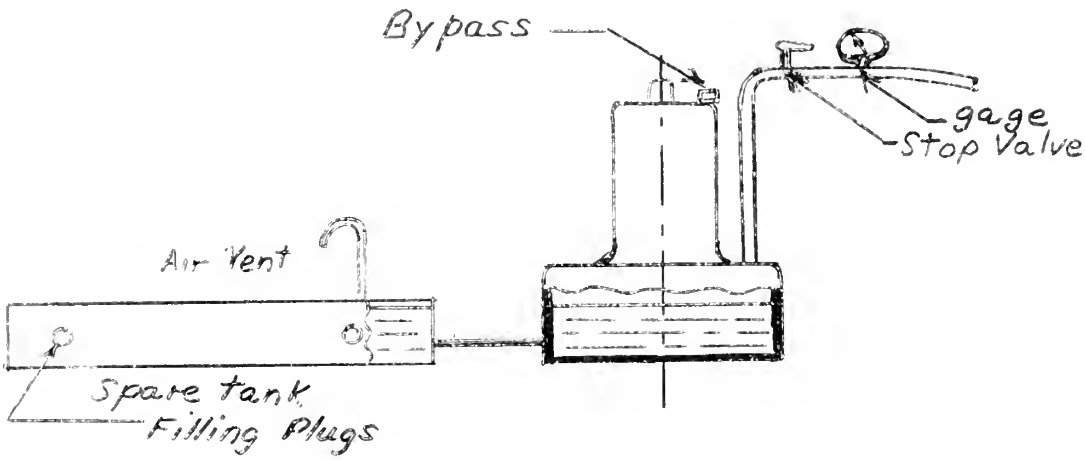
The pump supply of twenty-six cubic inches per minute indicated that seven rams could travel at a maximum rate of approximately 5/7 inch per minute. The authors felt that this capacity was just adequate for the latter part of plate-buckling runs when yielding conditions were to be experienced. The actual tests bore out this prediction.

The intermittent rating of 10,000 psi. proved somewhat disappointing under actual test conditions. It had originally been believed by the authors that continuous rating referred to production conditions, whereas the intermittent rating would be entirely applicable to the test conditions contemplated. The hydraulic pressure required for the 280,000 pound capacity of the machine is 7750 psi. Actual test runs showed that careful attention to the pump operating temperature was necessary when it was operating at 5,000 psi or greater. This limitation caused difficulty in buckling the first plate and prevented prolonged test runs which allowed full yield at higher loads.

Considerable difficulty was anticipated with the problem of pump

Figure 26

Hydraulic Pump Characteristics



<u>Specifications</u>*

General: Pump tank: 1 gallon capacity
Recommended oil: a DTE light oil.
Pressure hose connection: 3/8" female pipe tap.

Motor: 1/2 HP ball bearing repulsion induction, 1725 R.P.M., 110 volt 60 cycle AC.

Pump: Type: wobble plate
Pistons: 4 5/32" diameter with 1/4" stroke
Oil capacity: 26.8 cubic in./minute
Pressure: continuous service 5000 psi.
intermitten service 10,000 psi.

Model: P-182 manufactured by Blackhawk Mfg. Co.
Milwaukee, Wisconsin.

* Blackhawk Bulletin No. PM-46

control. Hydraulic controls can experience self-oscillation similar to feed-back servo systems. The fact that relatively thin plates were to be placed on edge in the loading system and tested to destruction meant that practically speaking a spring of variable K would be placed in the hydraulic control system. The possibility of a resonance condition existed from self-excited vibrations. To properly design the control system to insure avoiding the hunting effect would involve good estimates of not only the varying spring constants of all the plates tested, but also the effective spring constants of the rams, oil compressibility, and other parts of the system. This effort was not considered expedient and a calculated risk was taken.

Two systems of pump control were proposed by the Blackhawk Manufacturing representative. One system employed a separate bypass valve so that control could be achieved through a division of pump supply between the exterior recirculating system and the ram supply line. This system was considered unsuitable because of doubt that a positive shut off could be obtained. The system actually selected made use of the adjustable bypass valve already installed in the pump with the addition of a needle valve in the ram supply line. Between the needle valve and the ram manifold, a 10,000 psi capacity hydraulic gage was installed for rough load measurement.

As originally designed, it was anticipated that a rough setting of the bypass valve would be made, while fine control would be achieved through use of the needle valve. This system was entirely practical for short-duration, full load runs. However, plate testing required long periods of time at high loads. The throttling effect of the needle valve meant that the pump would have to operate at higher pressures than the

pressure required for the load on the machine. Overheating and stalling of the pump resulted from this cause on the first plate test. Thereafter, the needle valve was used only as a shut-off valve except at low pressures. Fine control was successfully achieved through careful use of the pump bypass valve alone.

Some hunting effects were noted in plate test runs. However, it is difficult to say whether these effects resulted from self oscillations or from the effects of too large an adjustment of the bypass control valve.

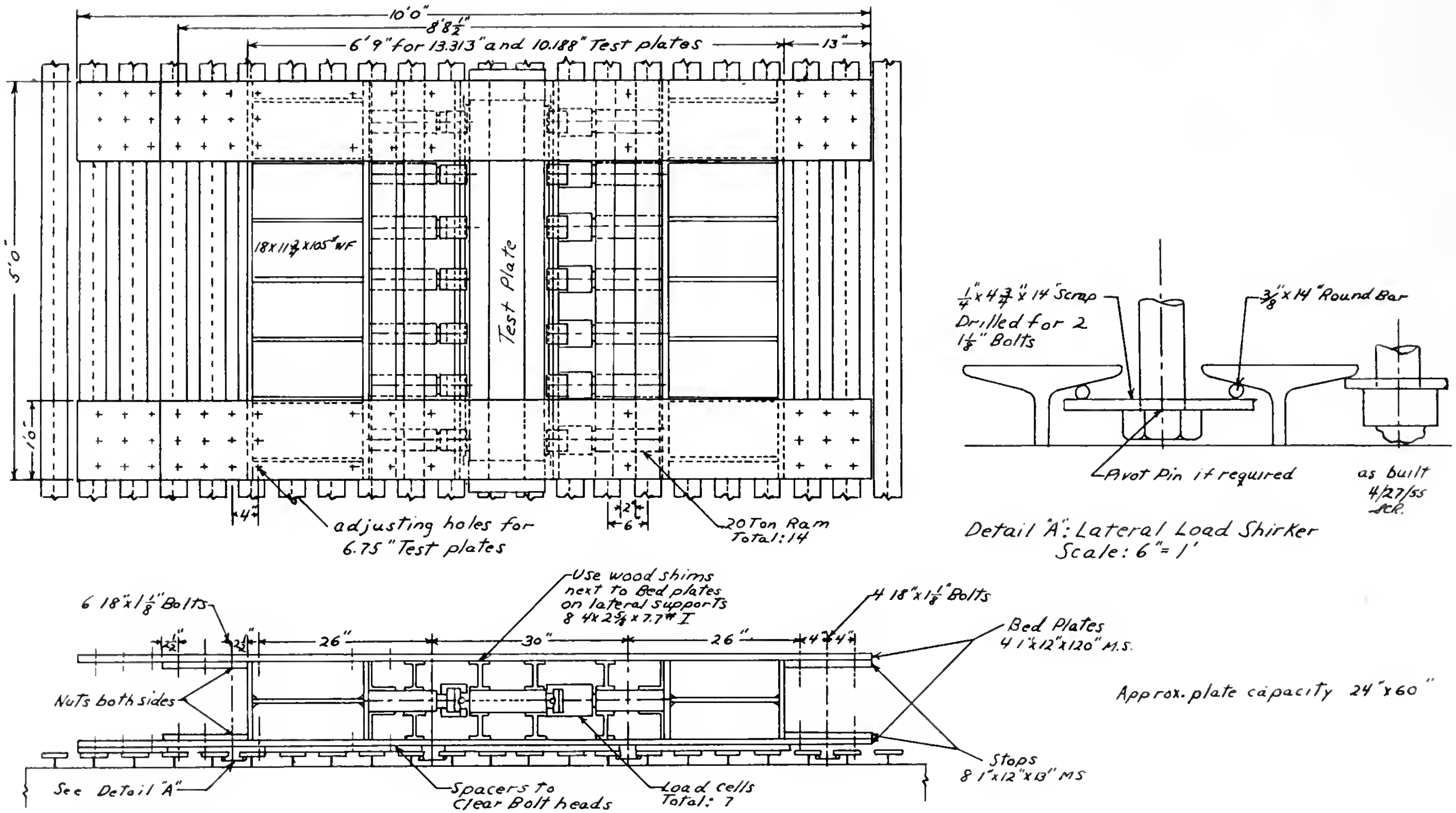
Because of the leakage problem, it was necessary to provide means for refilling the parasite rams. An extra length of hose was provided to be connected between ram manifolds when refilling was required. The drawback in this system is that the load applying rams must be prevented from being filled during the replenishment of the parasite rams.

c) Test Framework (see Fig. 27)

The design of the test framework had two major objectives, viz. to correct previous difficulties by providing adequate lateral restraint and to hold the two eighteen inch I-beam test heads up to the proposed 280,000 pound loading. While the test bed in the Ship Structures Laboratory consisted of both a vertical wall and a horizontal floor, it was considerably easier to design the machine in the horizontal position. The only possible major drawback to changing Pittman and Rinehart's testing jig from the vertical to the horizontal lay in the introduction of additional contour in the plate caused by the plate's own weight. Theoretical calculations using Levy's solution showed that the worst maximum deflection in the contemplated test series would be 0.017". [6] This amount is considered insignificant because of the relative

FIGURE 27

TEST FRAME



Needed Material:

4 1"x12"x120" M.S. Bed Plates Drilled for 1⅛" Bolts
8 1"x12"x13" M.S. Stops Drilled for 1⅛" Bolts to match
18 18"X1⅛" M.S. Bolts threaded 15"
56 3"x1⅛" M.S. Bolts
110 1⅛" Nuts for above
8 60"x 4"x2⅝"x 7.7# I or other suitable compressive lateral support
Load Cells and hydraulic pump

280,000 # Compression Machine

Designed for Test Bed in Bldg #41

MIT 1/11/55

Scale: 1"=1'

JCR.

inaccuracies of other measurements, and, more important, since this gravity-induced deflection could be used to partially compensate for plate unfairness due to other causes.

The test bed itself was needed to provide a plane of reference, support for the great weight of the test machine, and to prevent large lateral distortions under load. Some form of tensile restraint was needed to prevent the large I-beams that were to serve as heads for the test machine from moving apart. Since bending loads in these tensile members could be provided for in other ways, large flat plates, hereafter called bed plates, could be employed. Since full travel of both sets of rams was less than 10", the frame would have to be provided with a means of gross adjustment for varying plate sizes. It was felt that the simplest solution lay in a system of four bed plates with adjustable, bolted stops. Through-bolts were provided at these stops to counteract the movement of the eccentrically applied tensile load. The through-bolts between the heads were provided to counteract the effects of the lateral load from the ball bearing races. All through-bolts were connected to the test bed to insure that the test machine remained planar under load.

Considerable difficulty was anticipated in preventing the light I-beams of the concrete test bed from taking no more than a small portion of the test machine load. The load would be transmitted by means of friction between the bottom bed plates and the concrete test bed I-beams, and by means of shear in the through-bolts. The friction effect was minimized by use of wood spacers which have a low modulus of elasticity. These wood spacers served the additional purpose of allowing room for the stop plate bolt heads. An elaborate lateral load shirker was designed

as a means of minimizing through-bolt shear. Unfortunately, the bolts which were actually received had considerably thicker heads than anticipated, and the lateral load-shirker could not be fitted. As an expedient, standard washers were used. In defense of this expedient, it can only be stated that a load of 240,000 pounds has been successfully applied to the machine with no damage to the test bed.

Attention was paid to the fact that load was transmitted from the bed plates to the heads at the outboard edge of the flange of the 18" I-beam. However, it was felt that local yielding would transmit this load through the flange stiffeners to the web of the I-beam. Considerable care was used to insure that all the stop bearing surface did indeed touch the I-beam flange. Considerable trimming of the I-beam flange support was required to provide this close fit.

Holes were drilled in the bed plates to allow for adjustment of the stops at one end of the machine in four inch steps so that the machine capacity could be adjusted from approximately 6" to 24" in line with the load. Through-bolt holes were also provided in similar steps. It should be noted that, in some cases, six instead of four through bolts were needed for overcoming the couple caused by the eccentric tensile load on the bed plates. Importunate spacing of the concrete test bed I-beams dictated this expedient.

Lateral restraint of the ball bearing raceways turned out to be extremely easy to provide. A simple system using 4" I-beams was designed. An unforseen dividend developed in that the lateral restraining I-beams provided the framework for a packaged test unit consisting of the ball bearing raceways, test specimen, segments, and all necessary test specimen wiring. Two of the I-beams were screwed to the underside

of the ball-bearing raceways. The other two I-beams were placed on top of the raceways at the beginning of each run. Adjustments for eccentricity were made by using hardwood shims. The unforseen simplicity of the rig was that the test package could be prepared elsewhere and merely slid into the side opening of the machine without loosening the top bed plates.

Another improvement in lateral restraint was provided by four additional 4" I-beams between the ram bodies and the bed plates. This modification meant that lateral restraint was provided closer to the pin joints than before. Use of these I-beams permitted more accurate alignment of the lines of action of the rams. Brass shims were necessary under the bases of the set of rams carrying the load cells to obtain alignment.

In order to provide a strong test piece for cycling purposes, one of the 8" wide flange I-beams was adapted for use. A 1" round bar was tack-welded to each flange of the I-beam to simulate the segmented b-edges of the test plates. Hardwood blocks and hardwood shims were fabricated to supply lateral restraint in a manner similar to the 4" I-beams previously mentioned.

A considerable margin for overload is allowed in all parts of this machine. Specifically, it was assumed that some uneveness of loading might occur in the bed plates. Each bed plate was therefore designed for a total load of 100,000 pounds, which meant a unit stress of 11,000 psi., allowing for all lost material. Navy riveting specifications for chain riveting were followed for bolt arrangement and spacing. Maximum bolt loadings for minimum cross-sectional area with no allowance for stress concentrations were established at 10,000 psi. in shear, and

15,000 psi. in tension. The lateral restraint I-beams were sized by space requirements alone. No buckling of the webs has been noted nor is any anticipated, although calculations have not been carried out. No calculations were carried out for either the concrete test-bed I-beam or the means for attaching the through-bolts to them. In both previous cases, an estimate of the loading is purely arbitrary.

In summary, the weak points of design should be listed for anticipation of difficulties in future projects. The I-beams of the concrete test bed and the means of attachment thereto should be watched carefully for signs of failure. Buckling of the webs of the lateral restraint I-beams under highly eccentric loads would necessitate the use of specially rolled or fabricated sections. Finally the through-bolt nuts becoming loose under repeated use will probably indicate yielding and necessitate the replacement of the bolt.

d) Load Measuring System

The major problem in designing the load measuring system for the new test machine was to measure the actual total load on the plate edge, independent of all friction effects. For this reason, it was felt that a system of seven load measuring devices placed between the rams and the hardened steel loading bar was necessary. The plate would then be subjected only to the forces supplied by the load measuring devices, the ball bearing raceways, and the opposite ram heads. The effects of variations in friction and retraction spring forces in the rams could therefore be measured.

The load measuring devices would have to have an accuracy dependent on the particular plate to be buckled. An inaccuracy of 1/2% of 280,000 pounds would in truth be 4% for some of the plates to be tested, since

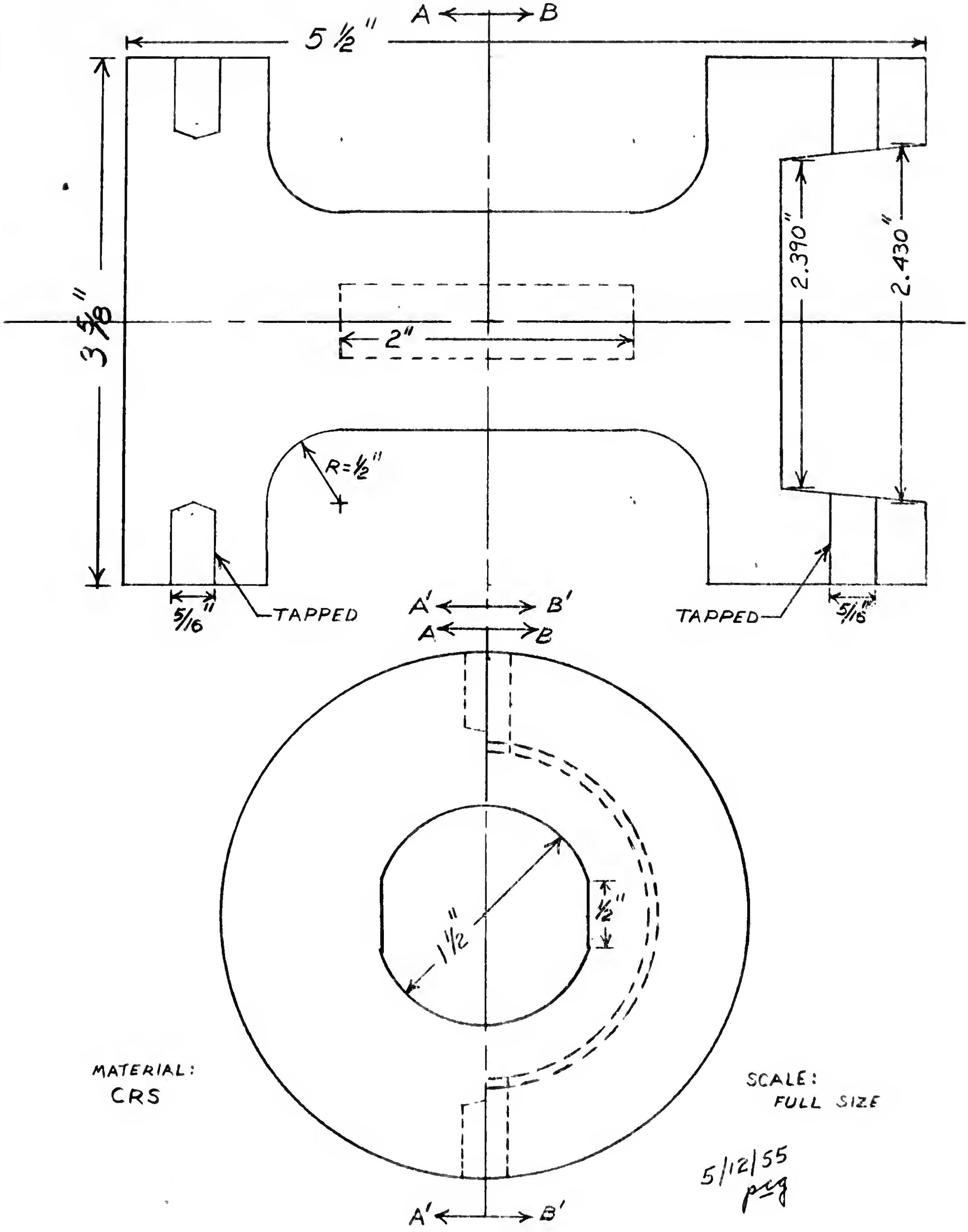
these plates were expected to fail at approximately 30,000 pounds load. In addition, a sensitivity commensurate with the required accuracy was a necessity. While linearity of response was not a requirement, it would facilitate data reduction.

Previous studies by the authors in the Experimental Stress Analysis Laboratory had indicated that a stress averaging system of many load cells was practicable. A system of seven load cells, placed between the rams and the hardened steel loading bar was decided upon. To gain in sensitivity and to provide inherent temperature compensation, two axial and two circumferential strain gages on each cell were decided upon.

The shape of the load cell was a compromise between a desired thinness for increased sensitivity, stability under compressive loads, connections to the rams, and to the hardened steel loading bar, and uniform stress distribution for proper function of the strain gages (see Fig. 28). To eliminate bending, the strain gages had to be mounted diametrically opposite to each other. Furthermore, the gages had to be in line with the narrow plate so that maximum sensitivity would be insured. Linearity and repeatability of strain gage response limited stresses to the proportional limit. Special steels with high proportional limit were not considered because of poor machinability, which resulted in high costs. Non-linearity of response ruled out the use of aluminum even though some increase in sensitivity would have resulted. Mild steel was originally chosen, but the machinist supplied corrosion-resistant steel which does not have a materially different proportional limit.

Since each load cell must carry up to 40,000 pounds, the proportional limit of 25,000 psi. determined the cross-sectional area of the main body of the load cell. A diameter of 1.500" ± 0.002" was actually

FIGURE 28
LOAD CELL



chosen, based on a full load stress of 22,900 psi. (see Fig. 28). Flats were ground on the cylindrical portion of the load cell to a depth of 0.036" for good adherence of the gages. Loss in cross-sectional area is negligible. In order to secure the load cells to the ram heads, set-screws were used. The two inch tapered Briggs thread prevented a threaded coupling because it is difficult to machine the thread so that loads will be transmitted to the bottom of the female end of the load cell and not through the threaded joint. The latter condition will cause varying stress patterns near the load cell strain gages since the seating conditions may not be exactly repeatable. The one-inch depth of the female end of the load cell was dictated by the need for cantilevering the load cell and the hardened steel loading bar. The other end of the load cell was given a 3-5/8" diameter to provide the support for the special C-clamps and the hardened steel loading bar.

Allowing for transition fillets, the size of the axial and circumferential strain gages determined the length of the parallel middle body. A compromise was made between ease of attachment and adequate sensitivity by using Baldwin A-7 strain gages as circumferential gages near the rams, and Baldwin A-3 gages as axial gages.

Calculations of the load cell sensitivity showed that a sensitivity of approximately seven micro-inches per inch per 100 pounds of load could be expected. A rash presumption was made that seven load cells would give seven times this sensitivity. Actual tests proved what had been forgotten, viz. multiplying the number of gages in one arm of a strain indicator merely averages the measured strains unless the bridge supply voltage is increased. Efforts were made to correct this mistake by using an Ellis amplifier, an oscilliscope, and an increased voltage

supply as a substitute for the Baldwin Strain Indicator alone. The supply voltage of the Baldwin Strain Indicator cannot be increased. The substitute system of recording could not be sufficiently shielded to attain sensitivity similar to the strain indicator alone. Therefore, efforts in this direction were discontinued, and a sensitivity of approximately 0.3 micro-inches per inch per 100 pounds per seven load cells was accepted.

An interesting problem developed regarding the proper electrical arrangement of the load cell strain gages in the arms of the Wheatstone Bridge. Of course, axial gages and circumferential gages would have to be in opposite arms of the Wheatstone Bridge. But the Baldwin Strain Indicator linearity limits were stipulated by the manufacturer as eighty to five hundred ohms per arm. In this case, each arm would have to contain seven 120-ohm gages. Any series parallel arrangement of gages will average the strains of all the gages if the strains are identical. But the friction and other variations in this case meant that each load cell would experience a slightly different load. In every case, except the pure series or parallel strain gage system, one strain will be weighted with respect to another in the averaging system.

To illustrate the phenomenon and to show the compromise solution arrived at in the seven load cell system, Table III is arranged on the basis that a perfect average is obtained with seven gages in series. It is further assumed that one strain is twice each of the other six. This double strain is then placed in various positions in the practicable circuits.

Results of these calculations show that three series gages in parallel with four series gages shows the least effect. To further reduce

TABLE III

Practical Seven Gage Circuits for Minimum Weighting Factor

Hypothesis: (1) Gage R = 120 ohms.

(2) Strain induces ΔR of 1 ohm in 6 gages.

(3) Strain induces ΔR of 2 ohms in remaining gage (as starred).

(4) $\Delta R/R$ proportional to strain

(5) Weighting factor equals (WF)

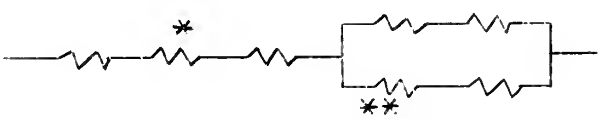
$$\frac{\text{weighted average strain}}{\text{perfect average strain}}$$

Case A (perfect average)

Total R = 840 ohms (too high)

* Total $\Delta R/R = 1/105$ WF = 1.0

Case B

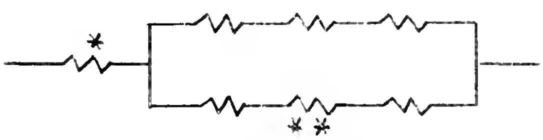


Total R = 480 ohms (satisfactory)

* Total $\Delta R/R = 1/96$ WF = 1.095

** Total $\Delta R/R = 1/114.2$ WF = 0.918

Case C

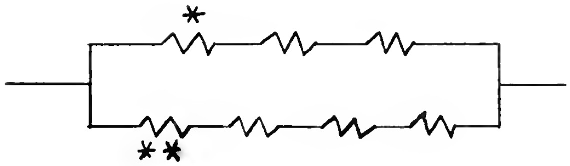


Total R = 300 ohms (satisfactory)

* Total $\Delta R/R = 1/85.7$ WF = 1.225

** Total $\Delta R/R = 1/110.5$ WF = 0.95

Case D



Total R = 206 ohms (satisfactory)

* Total $^{\Delta R}/_R = ^1/_{110}$ WF = 0.955

** Total $^{\Delta R}/_R = ^1/_{103}$ WF = 1.020

the possible error, the gages of #4 load cell were placed alternately in the series branches with 1, 2, and 3 or 5, 6, and 7 load cells in the arms of the Wheatstone Bridge (see Fig. 29).

The ultimate use of three load cells presented little problem, since three gages could be put in series totaling 360 ohms. This resistance is well within the linearity range of the Baldwin Strain Indicator. Further, the arrangement is inherently a true average.

A wiring system was required to carry out both the series parallel and plain series arrangement of gages. It was felt that wiring the gages at the load cells was not desirable because movement of load cells relative to one another could vary terminal contact resistance. Therefore, a system was designed so that leads from each gage were led to a switchboard. The switchboard was designed so that each load cell could be read individually, or the seven load cells could be averaged. By shorting out two gages and opening certain switches, a three-cell series arrangement could be easily attained. Capacitance was reduced by using four-lead cable and binding each pair of load cell cables together. Screw terminals were used at the load cells so that the load measuring system wiring could be moved independent of the load cells and strain indicator (see Figs. 30, 31).

2. <u>Procedure for Setting up Equipment</u>

a) Setting up Equipment for Calibration

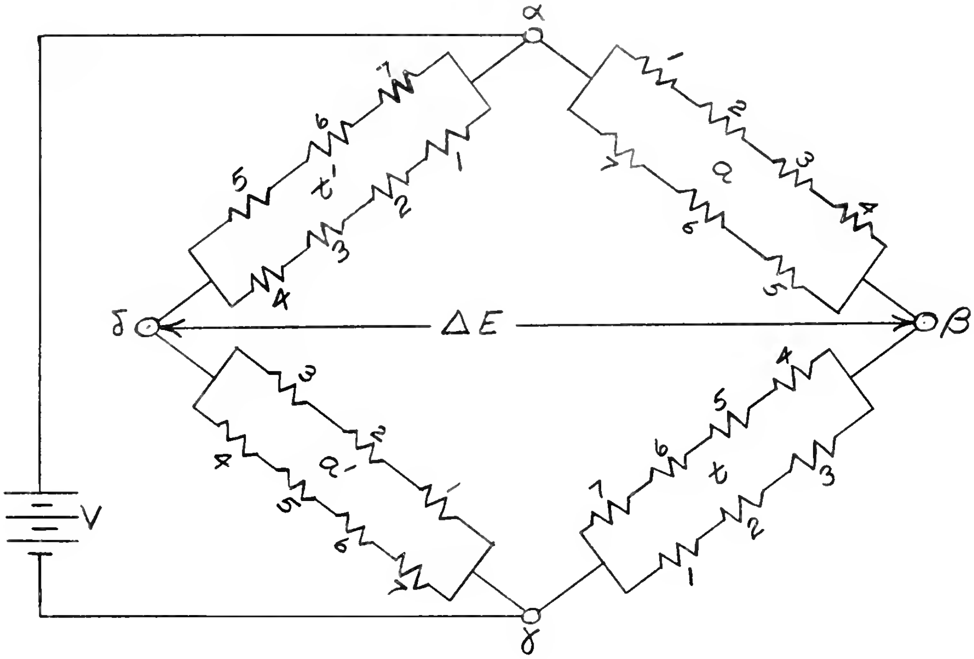
Recalibration of the test machine will be necessary from time to time. For this reason, a careful description of the calibration procedure follows.

The basic units required for calibration are:

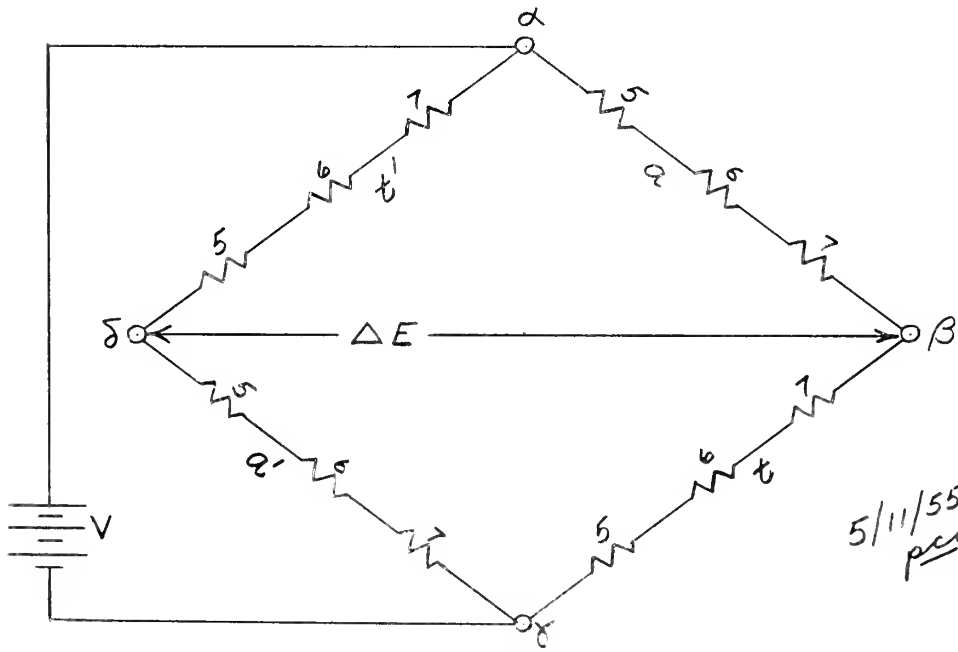
1. Both heads, including the large nut and spacer ring for the

FIGURE 29

WHEATSTONE BRIDGE ARRANGEMENTS



(a) SEVEN LOAD CELLS



(b) THREE LOAD CELLS

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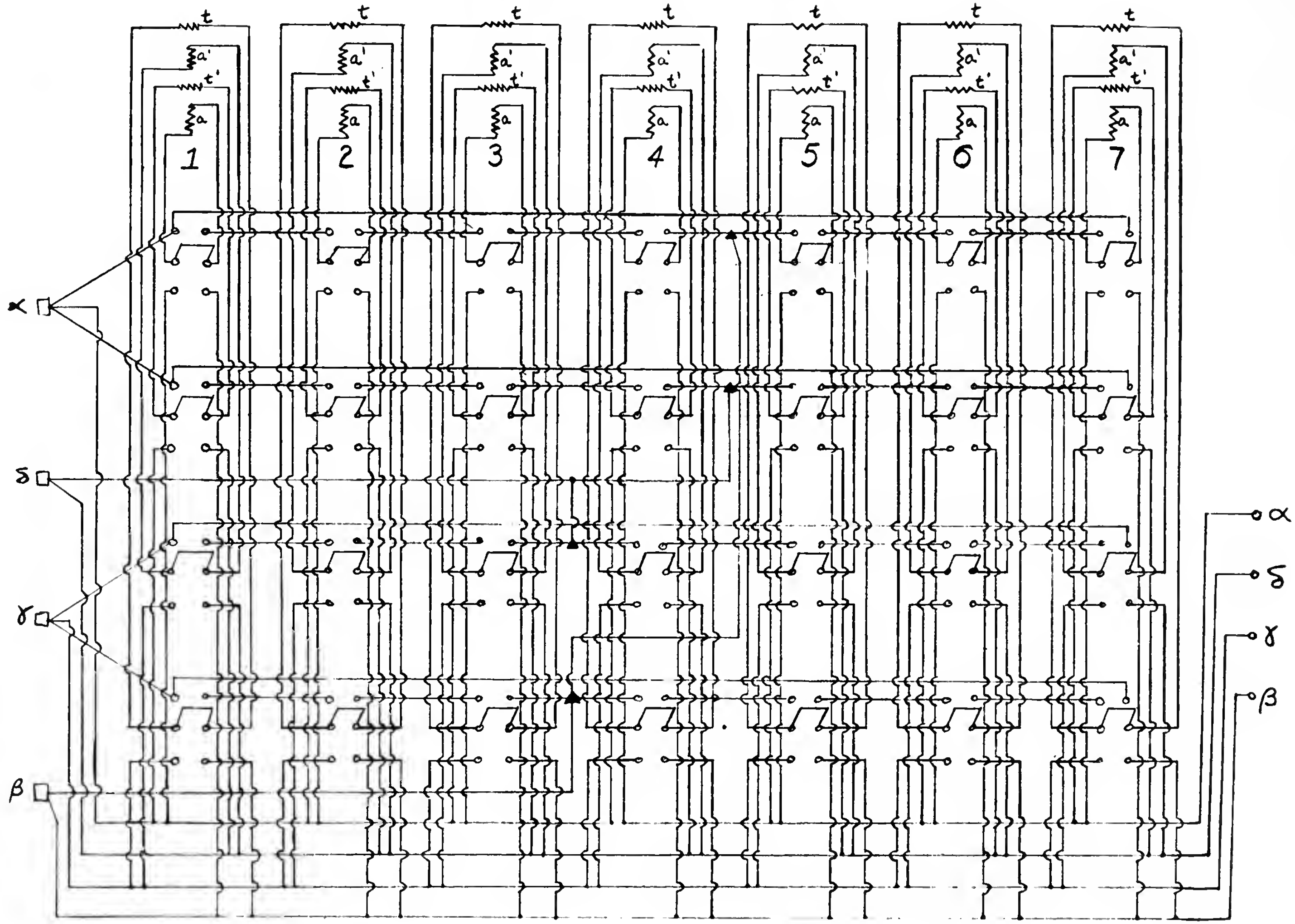
pcg

Figure 30
Switchboard Wiring Diagram



upper head, and flat bar shims for aligning.

2. Seven load cells, ram unit to which they are attached, and associated hydraulic hoses and manifold.

3. Pump without spare reservoir.

4. Load cell switchboard, and associated wiring.

5. A Baldwin Type L strain indicator.

6. Five feet of 1" round bar.

7. One of the two hardened steel loading bars.

The pump unit need not be included unless a check of the oil pressure gage is required, or a check of pump control is desirable.

The major problem in making a calibration check is the safe movement of the heavy equipment from Building 41 to Building 1. A four-chain sling must be used for handling the large heads which weigh approximately 900 pounds each. One head at a time may be moved to the receiving entrance of Building #1, where hoisting equipment is available. The reason for the load limit is that whereas the elevator between the basement and street level of Building 41 has a safe capacity of one ton, the elevator has been put out of commission on previous occasions by loads of more than 1/2 ton. It is not necessary to separate the ram unit, load cells, and test head for transportation if a spreader is used with the four-chain sling to protect the load cells. One of the buckled test plates may be used as a spreader.

After the equipment is hoisted into the Materials Testing Laboratory, the upper and lower heads are placed in the 300,000 pound testing machine in accordance with procedure outlined by Pittman and Rinehart. [5]. In essence, this procedure consists of using a small dolly to place the upper head (fitted with a stud) under the upper head of the 300,000 pound

test machine. The upper head of the test machine is then lowered over the stud, and a large washer and the nut are used to secure the I-beam to the test head. Care should be taken that the under surface of the I-beam is maintained horizontal by use of suitable shims. After raising the upper head, the lower I-beam, complete with rams and load cells, is jockeyed into place over the lower head. Again, care should be taken to shim so that the rams are vertical and approximately centered under the upper head.

The hardened steel loading bar is merely laid on top of the load cells. The round bar is then placed in the milled groove of the loading bar. No lateral restraint is required for loading this arrangement up to 220,000 pounds (and possibly more) if care is taken to minimize eccentricity.

Leads from the load cell switchboard may now be connected to the particular load cells required for the test (see design section for two particular arrangements). The load cell switchboard is best placed to either side of the test machine. The leads to the strain indicator may now be connected as shown in the diagram on the switchboard itself. Some difficulty will probably be experienced in balancing the strain indicator. This difficulty can usually be corrected by cleaning the contact surfaces of the knife switches with carbon tetrachloride. In addition, loose wiring should be looked for since vibration induced by moving invariably loosens the screw terminals. A steady, non-drifting zero unaffected by movement of the switchboard must be obtained before accurate calibration runs.

The pump may then be connected to the ram manifold, and the rams given about a one inch extension to allow for depression of the ram

pistons under loads. The pump may be used for the calibration runs if desired.

The actual calibration runs should be carried out with two operators. One man may apply the load in given steps, reading off both total load and hydraulic pressure. The other man would then read the load strain indicator and record all information.

Three total load gages are available with ranges of 0-30,000 pounds, 0-150,000 pounds, and 0-300,000 pounds. Each gage is supposed to be accurate to A.S.T.M. standards of 1/2% of its maximum range. Therefore, ideally, a run to loads above 150,000 pounds should employ each of the three gages in succession. However, extreme difficulty was experienced by the authors in making the three gages agree at the transition points on both the up and down parts of the run. Therefore, only the gage with the smallest possible range was used for each run. The ideal procedure should be attempted by anyone recalibrating. The necessary number of loading cycles to get a repeatable zero should be made before calibration runs are attempted. A zero shift of less than ten micro-inches would be a permissible standard. If good correlation is obtained, only three complete runs need to be made. However, a series of ten cycles to one-half load should be made to check scatter.

The disassembly and moving of the calibrated rig is essentially the reverse of the previously described procedure.

b) Setting up test machine for plate buckling tests (see Fig. 27).

Since the test machine occupies most of the concrete test bed, it is probable that the machine will be broken down when not in use for long periods of time. Therefore, a detailed assemply description is believed necessary. The following pieces are necessary for assembly:

1. Four ten-foot bed plates

2. Eight stop plates

3. The two 18" I-beam heads

4. The two seven ram assemblies

5. Eight 4" I-beams

6. Eighteen 18" x 1-1/8" through-bolts

   Fifty-six 3" x 1-1/8" bolts

   One hundred ten nuts for these bolts

   Eighteen large washers

7. Wood spacers to be placed between bed plates and test bed

8. Ball-bearing raceways for the plate sizes to be tested

9. Two hardened steel loading bars

10. Segments required for particular plate size

11. Three flat bar shims for stop plate adjustment

    Brass shims for ram alignment

    Hardwood shims of assorted sizes for lateral restraint wedging

    Spring steel shims for segment fitting

12. The P-182 high-pressure pump with associated control valves, and pressure gage

    The extra oil reservoir

13. Seven load cells

    Two pair of the special C-clamps

    Corrugated cardboard in strips

14. Load cell switchboard

15. The H-beam cycling piece

    Four hardwood blocks for lateral restraint

16. The strain indicator used for calibration runs

17. Instrumentation for test specimens including angle bar for dial gage if desired.

A carpenter's chalk line should be used to lay off two reference lines on the test bed I-beams for the outboard edges of the bed plates. The through-bolts are then fitted with the washers and slid between the test bed I-beams as shown in Fig. 27. Six or four through-bolts are used at the adjustable end of the test machine as dictated by the required restraining moment (see section VII-B-1-c, Design of Test Frame). Lay in wood spacers using reference lines.

The stop plates are then bolted to the bed plates using short bolts, leaving the required number of holes for through-bolts. Nuts are secured hand-tight. Each bottom bed plate is then lowered, stop plates up, over the through-bolts, being careful not to damage the through-bolt threads. The job is made considerably easier if the bed plate is supported at only its center of gravity, and one end at a time is fitted over the through-bolts. One set of through-bolt nuts are threaded on and made hand-tight.

The ram unit used for load application is then secured to the 18" I-beam that has no stud. The other ram unit is secured to the remaining 18" I-beam. Each complete head unit is then rotated onto its side, using the four-chain sling and a crowbar. Each unit is carefully lowered between the through-bolts against the stop plates. The head with load applying rams is placed at the non-adjustable end so that the I-beam base plate lies between the test bed I-beams. The second set of through-bolt nuts is put in place just below the level of the test heads. The remaining bed plates with their stop plates down are then lowered into position, and the third set of through-bolt nuts made hand-tight. The

three flat bar shims will have to be used ahead of one pair of stop plates for proper fit.

Four 4" I-beams are lightly wedged into place next to the rams using hardwood shims. The ends of the seven load applying rams are wrapped in one inch wide pieces of corrugated cardboard, so as to provide a snug fit for the load cells. The load cells are then fitted to the rams, matching the numbers on the load cells and the rams. Care should be taken to align the set screws vertically. Fit the specially designed C-clamps to the end load cells. Slide in the hardened steel bars such that they are held by the C-clamps. Slide in the H-beam cycling piece, so that it is between the two bars. Block the H-beam so as to provide alignment of the test piece round bar to the milled grooves on the loading bars.

Place the P-182 pump in a convenient position (preferably by the switchboard) and connect it to the manifold of the load applying rams. The filling connections of the spare reservoir require that it be filled while on edge. Therefore, the reservoir is connected to the pump while the reservoir is on edge, and the pump is blocked to a suitable height. The pump is then lowered to the floor while the reservoir is rotated very carefully. The reservoir should be blocked to maintain equal elevation of reservoir and pump sump.

A pressure of 500 psi. is slowly put on the rams to align all stop plates, and to check for major hydraulic leaks. All 1 1/8" nuts are then slugged tight, except those on the under side of the top bed plates. The nuts under the top bed plates are available for bowing the top bed plates, should the need arise. The machine load is then removed, and the rams carefully aligned using a spirit level. The spirit level is used on the

ram bodies and between the centers of the milled slots in the hardened steel loading bar. Relatively soft, brass shims under the bases of the rams should be used for this purpose. The desired lateral ram spacing is then selected, and the 4" I-beams are firmly wedged. The angles which provide support for the ram bases should then be made secure. The H-beam should be realigned and firmly wedged. A hydraulic pressure of 6,000 psi. (a load of 220,000 pounds using seven rams) is then slowly applied. Considerable creaking will be noted, but the points to be watched are lateral movement of the H-beam or rams, or bowing of the bed plates. Of course, signs of failure in the concrete test bed should always be looked for.

The load cell switchboard is then clamped to the wall. If three load cells are to be used for measuring load, switch systems 5, 6, and 7 should be connected to load cells 3, 4, and 5. And switches 4a and 4t' should be shorted out. All other switches should be placed in the open position. The color code is used to connect the leads to the load cells. If seven load cells are to be used for measuring load, all switches are to be thrown toward the load cell leads, and the leads connected to their matching load cells. If a single load cell is to be used, all load cell switches except those connected to the desired load cell are to be opened, and the remaining four switches thrown to a position opposite the load cell leads.

The load cell strain-indicator may then be placed next to the pump. The leads from the switchboard are connected to the strain indicator using the diagram on the switchboard.

If a test is contemplated within two hours, the system should be cycled to 6,000 psi. hydraulic pressure a sufficient number of times to

get a repeatable zero on the strain indicator. A zero shift of 20 micro-inches was considered acceptable by the authors. The H-beam is then removed from the machine. The machine is now ready for the test specimen.

Combinations of three, five, or seven rams on each side may be used for different load capacities, different sensitivities, and different load distributions. To remove rams from the system, it is necessary to disconnect the Spee-D-Couples at the rams. The coupling on the loose end of a hose should hold against the oil pressure, but, if it does not, the particular line must be removed from the manifold, and the hole capped. Before disconnecting the rams, it may be necessary to force them to retract using a crowbar. Using only three rams requires use of the lower half of the C-clamps which hold the hardened steel loading bar. Using the upper half of the C-clamps would short out load cells number 3 and 5. Load cells #1 and #7 are constructed in a manner which allows the use of both top and bottom C-clamp. When five rams are used, cells #1 and #7 replace cells #2 and #6, leaving rams #1 and #7 retracted and disconnected. During the use of the machine it will be necessary to check the tightness of the set screws of the load cells which provide support for the hardened steel loading bar.

Two of the four remaining 4" I-beams are secured to the desired pair of ball-bearing raceways at the spacing required for the test plate. The assembly is then set with I-beams down at a suitable working height. Wiring is connected to the test plate strain gages as required and passed through the I-beam assembly to prevent damage to the wires. The test plate is slid into the ball-bearing raceways with any unfairness concave down. The ball-bearings are shimmed in place and tightened using

Allen set-screws. Resin-core solder, spring-steel shims and segments are then attached to both free edges as described by Pittman and Rinehart [5]. The wires and gages can then be checked with an ohm meter for grounds and continuity. The test assemblage is slid into the side opening of the machine. The other two 4" I-beams are then slid into place. Alignment is checked before the assemblage is firmly wedged with hardwood shims. Electrical connections are completed, and the electrical system load cells and test specimen should be checked for grounds. The angle bar with the machined edge for dial gage traverses may now be placed across the bed plates and clamped. A period of no more than one to two hours should elapse between the last loading cycle on the H-beam and the specimen test. Otherwise load readings at high loads will be unreliable. It should be noted that oil pressure gage readings are unreliable due to the Bernoulli effect caused by oil leakage and ram travel.

Breakdown of the test machine and test specimen assemblage follow essentially the reverse of the above procedure. It should be remembered when breaking oil lines, that the ram retraction springs maintain a low oil pressure unless rams are fully retracted.

c) Load cell assembly

Because the insides of the load cells are partly masked, a detailed description of the assembly of the load cells is felt necessary to allow replacement of strain gages, repair of wiring, etc. The A-3 gages are aligned axially while the A-7 gages are circumferential. All gages are coated with wax as an added precaution, although replacement gages need not be coated. The gages are wired to brass bolts on the under side of wooden strips. This wiring has a simple color code using plastic spaghetti. The brass bolts are color-coded on the top side of the wooden

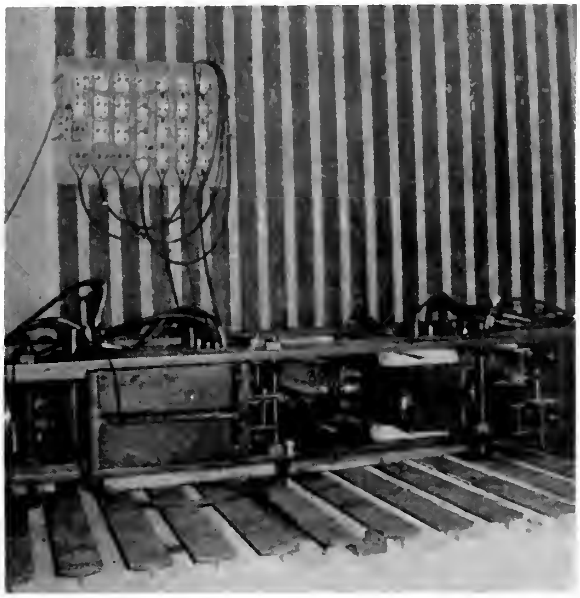
strips. The color-code follows:

	Gages	Load cell terminals	Spaghetti
circumferential gages	t	black	yellow
	t'	white	white
axial gages	a	red	black
	a'	green	green

The whole assembly is partly wrapped in electric tape to give some protection against side blows. The stiffness of the lead wires is a detriment in that direct blows are transmitted to the light gauge strain gage leads with no absorbtion. Therefore, care must be taken to prevent rough handling.

The following repairs have been made since calibration. An axial gage for number 6 load cell has been replaced due to a ground. A lead wire to another axial gage in number 3 load cell was broken next to the gage felt and repaired with a drop of solder.

Figure 31
New Test Rig with Switchboard



New test rig with cycling H-beam in place. Switchboard with leads #1, #2, #3, and #4 disconnected.

Figure 32

End View

Cycling H-beam in place. End jacks #7 disconnected. Note round bar bearing on hardened steel bar and hardwood spacers in place.

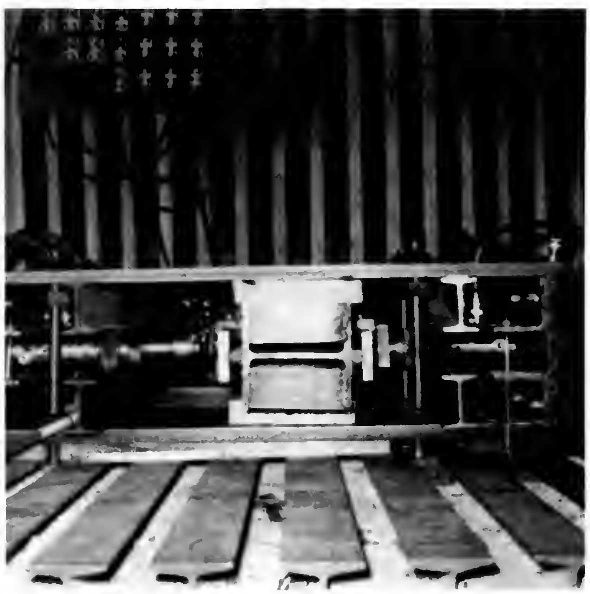


Figure 33
Test Plate

Test plate ready for the test apparatus. Ball bearing supports attached to lower I-beams, wires connected and segments in place.

Figure 34

Top View

Test Plate in place before inserting I-beams. Note load cells, wiring, and hydraulic hose couplings.

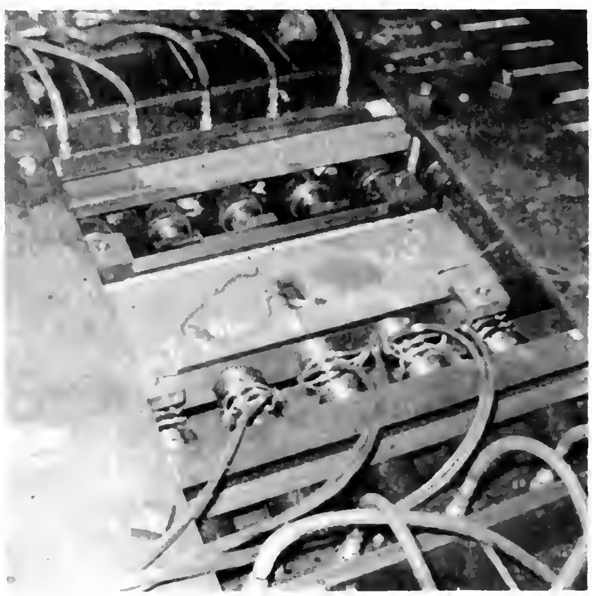
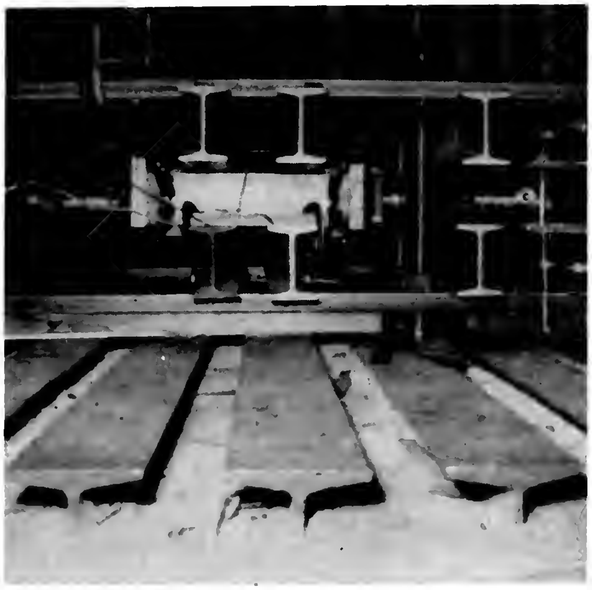


Figure 35

Side View



Test plate in place with upper I-beam inserted. Note angle in upper left corner used as track for dial indicator to measure deflections of the test plate's left edge.

Figure 36

Overall View

Test Apparatus

Figure 37

Control Station

Control station showing hydraulic pump, reservoir, and load indicating strain indicator.

Figure 38

Recording Station

Strain indicators used to measure strain on each side of plate.

C. SUMMARY OF DATA AND CALCULATIONS

TABLE IV-A

Plate Data

(a = 10.188" for all plates)

Plate Desig.	b (in)	a/b (in/in)	t (in.)	t' (in.)	A (in^2)	A' (in^2)
40-1/4-1	43.8	0.233	0.268	0.232	11.73	10.18
2	"	"	0.262	0.222	11.46	9.72
3	"	"	0.264	0.242	11.55	10.61
4	"	"	0.258	0.240	11.29	10.51
50-1/4-4	"	"	0.222	0.208	9.71	9.11
50-1/3-1	32.8	0.310	0.226	0.207	7.42	6.80
2	"	"	0.229	0.217	7.51	7.13
3	"	"	0.216	0.202	7.09	6.63
4	"	"	0.222	0.210	7.28	6.89
50-1/2-1	21.9	0.465	0.222	0.201	4.86	4.40
2	"	"	0.211	0.189	4.62	4.14
3	"	"	0.211	0.194	4.62	4.24
4	"	"	0.218	0.206	4.77	4.51
70-1/4-1	43.8	0.233	0.158	0.150	6.91	6.57
2	"	"	"	"	"	"
3	"	"	"	"	"	"
4	"	"	"	"	"	"
70-1/3-1	32.8	0.310	0.161	0.155	5.28	5.09
2	"	"	0.162	0.158	5.32	5.18
3	"	"	0.158	0.152	5.18	4.99
4	"	"	0.158	0.152	5.18	4.99
70-1/2-1	21.9	0.465	0.154	0.146	3.37	3.20
2	"	"	"	0.145	"	3.18
3	"	"	"	0.148	"	3.24
4	"	"	"	0.146	"	3.20

TABLE IV-B

Percentage Comparison of Theoretical
and Experimental Results

$$\frac{\text{"TOK"} - \text{Bleich}}{\text{Bleich}} \times 100$$

Plate Designation	Based on t	Based on t'
40-1/4-1	-28.6	+10.1
2	-30.5	+13.8
3	-21.0	+ 2.3
4	-44.3	-30.2
50-1/4-4	-32.4	-17.3
50-1/3-1	-13.0	+12.6
2	-30.9	-19.5
3	-20.4	- 3.1
4	-33.0	-20.9
50-1/2-1	-31.7	- 7.6
2	- 4.1	+40.3
3	-20.8	+ 2.1
4	-29.1	-16.4
70-1/4-1	-38.0	-27.5
2	- 3.3	+12.9
3	-17.9	- 4.3
4	- 5.4	+10.4
70-1/3-1	-25.8	-16.6
2	-40.5	-35.6
3	-21.7	-12.4
4	-14.4	- 4.1
70-1/2-1	+11.1	+30.0
2	+16.6	+26.6
3	+18.9	+34.4
4	+37.4	+60.5

D. SAMPLE CALCULATIONS

1. Determination of Load (P)

Taking calibration data (Table VI-A-C), linearity was verified by plotting. Total increments of micro-inches per inch for 95,000 pounds were determined for each of the three runs and the results averaged.

	Total Increment
Run #4	1696
Run #5	1694
Run #6	1691
average	1694 $\mu''/''$

Conversion factors were then determined for load application by three, five, and seven rams.

Three rams: $\frac{95,000}{1694} = 56.1$ pounds/$\mu''/''$

Five rams: $\frac{5}{3} \times 56.1$ pounds/$\mu''/''$

$= 93.7$ pounds/$\mu''/''$

Seven rams: $\frac{7}{3} \times 56.1$ pounds/$\mu''/''$

$= 131$ pounds/$\mu''/''$

Conversion factors were applied to the strain measured by the load cell strain indicator.

Example: 40-1/4-4 (seven rams)

$(0\text{-}12\text{-}100) - (0\text{-}10\text{-}1888) = 212\mu''/''$

$212 \times 131 = 27,900$ pounds

2. Average Stress

All buckling critical and ultimate loads were reduced to average stresses. The b edge length was considered as the distance between ball bearing supports for reducing experimentally determined loads to average stresses.

Thickness was considered as that determined by micrometer (t) and that determined by micrometer minus pit depths of both sides (t').

Example: 40-1/4-4

$t = 0.258''$

$t' = 0.258 - 0.18 = 0.240''$

$A = b \times t = 43.8 \times 0.258 = 11.29$ sq. in.

$A' = b \times t' = 43.8 \times 0.240 = 10.51$ sq. in.

$P_{ult} = 160.2$ kips

$$\sigma_{ult} \text{ (based on } t) = \frac{P_{ult}}{A} = \frac{160.2}{11.29}$$

$$= 14.17 \text{ kips/sq.in.}$$

$$\sigma_{ult} \text{ (based on } t') = \frac{P_{ult}}{A'} = \frac{160.2}{10.51}$$

$$= 15.27 \text{ kips/sq.in.}$$

3. Average Strain (ε_a)

The average strain at the geometrical center of the plate was measured as a means for qualitatively discussing results. Strains in the opposite faces as measured by strain gages were averaged.

Example: 40-1/4-4

(Top gage) (A-4-1008) - (A-4-979) = $\varepsilon_1 = +29\mu''/''$

(Bottom gage) (0-10-1587) - (0-12-0161) = $\varepsilon_2 = -574\mu''/''$

$$\varepsilon_a = \frac{\varepsilon_1 + \varepsilon_2}{2} = \frac{+29 - 574}{2} = -272\mu''/''$$

In some cases plate gage and dummy gage leads were interchanged and careful attention must be paid to the sign. Average strain must always be negative.

4. Strain Difference (δ)

The difference of strains between two opposite strain gages is a measure of lateral deflection. Taking values of section 3:

Example: 40-1/4-4

$$\varepsilon_1 - \varepsilon_2 = \delta = +574 + 29 = +603\,\mu''/''$$

The sign of the strain increment is important, an increase in strain denoting tension. The sign of δ is not significant except if a change in sign occurs in successive δ's.

5. Critical Load (Top of the Knee Method)

The plots of δ versus P are the bending curves. Intersection of tangents to the extreme ends of the curves give values of P and δ. The P value is the critical load determined by the "Top of the Knee" method and is converted to σ_{cr} as in section 2. The δ value is a measure of eccentricity and initial curvature. Therefore, plotting σ_{cr} and δ values obtained in a given series occasionally permitted an extrapolation to zero eccentricity and zero curvature. Results were poor and are only qualitatively presented in Section IV.

Example: 70-1/2 series

"TOK"	σ_{cr} (based on t)	δ
#1	9.62 ksi	720 μin/in
#2	10.1 "	40 "
#3	10.3 "	250 "
#4	11.9 "	95 "

σ_{cr} (extrapolated to $\delta = 0$) = 11.5 kips/sq.in.

6. Critical Load (Southwell's Method)

A plot of δ/P versus δ will give a straight line with a slope equal to the critical load [5]. Intercept with the δ axis will be a measure of the initial deflection of the plate [5] but this analysis was not attempted.

Example: 40-1/4-4

$$\delta = 603 \ \mu''/''$$

$$P = 93.4 \text{ kips}$$

$$\delta/P = \frac{603}{93.4} = 6.46 \ \mu''/''/\text{kip}$$

slope of δ/P vs. δ = 189.6 kips

σ_{cr} (based on t) = 16.8 kips/sq.in.

7. Critical Load (Donnell's Method)

A plot of P versus P/δ determines the critical load directly at the intercept of the curve with the P axis. The slope of the curve is the initial equivalent deflection [5] but was not determined.

Example: 40-1/4-4

$$\delta = 603 \mu''/''$$

$$P = 93.4 \text{ kips}$$

$$P/\delta = \frac{93.4}{603} = 0.155 \text{ kips}/\mu''/''$$

Intercept of curve with P axis = 188.3 kips

σ_{cr} (based on t) = 16.7 kips/sq.in.

8. Theoretical Critical Stress [2]

$$\sigma_{cr} = \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 K \qquad (1)$$

Example: 40-1/4-4

$E = 30.2 \times 10^6$ psi

$\nu = 0.3$ (assumed)

$b = 43.8''$ (unsupported length)

$a = 10.188''$

$$K = \left(\frac{b}{a}\right)^2 + 2.0 + \left(\frac{a}{b}\right)^2$$

$$= 18.58 + 2.0 + .0539 = 20.63$$

$\sigma_{cr} = 294{,}000\ t^2$ psi.

$t = 0.258$

σ_{cr} (based on t) $= 19.55$ kips/sq.in.

9. Modulus of Elasticity

For 1/4" specimen #2

$l = 2.552''$

$w = 0.850''$

$t = 0.252''$

Huggenberger $G.F._1 = 1055$

Huggenberger $G.F._2 = 1064$

At $P = 0$: $R_1 = 1.50$

$R_2 = 1.12$

At $P = 4400$: $R_1' = 0.89$

$R_2' = 0.27$

$$\sigma = \frac{P}{w \times t} = 20{,}500 \text{ psi}$$

$$\varepsilon_1 = \frac{R_1' - R_1}{GF_1} = \frac{-.61}{1055} \times 10^6 = 578\ \mu''/''$$

$$\varepsilon_2 = \frac{R_2' - R_2}{1064} \times 10^6 = \frac{.85 \times 10^6}{1064} = 799 \ \mu''/''$$

$$\varepsilon = \frac{\varepsilon_1 + \varepsilon_2}{2} = \frac{578 + 799}{2} = 689 \ \mu''/''$$

From plot of results

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{30,200}{1000 \times 10^{-6}} = 30.2 \times 10^6 \text{ psi.}$$

E. SUPPLEMENTARY DISCUSSION

1. Load Cell Creep

The phenomenon which has been noted with the seven load cells is a peculiar one. It is characterized by increased strain at high loads when the material has not been subjected to these high loads in the preceding few hours. It was possible to minimize this increased strain at higher loads by cycling (repeated loading and unloading). Fortunately, a measure of the effect is the difference of the zero readings of the strain indicator before loading and after the load is removed.

Precisely what this behavior should be called is open to some question. The material appears to act as if it were loaded beyond the elastic limit. And yet, the set in the material is not permanent, but is partially recovered after some time. Further, although cycling appears to "work-harden" the material, the lapse of time results in the return of the phenomenon even though most of the permanent set is retained.

Of course, the assumption cannot be made that the strain gages are truly measuring the strain in the material. The characteristics of stress and strain which are mentioned above could be caused by some creep or yield phenomenon in the glue of the strain gages or in the strain gage wire itself. Of major interest is how long a life the strain gages have because of this continuously increasing set. The manufacturer stipulates a permissible limit of one percent strain. This requirement limits the set to 10,000 micro-inches per inch per gage measured with the true gage factor setting. Correcting for the gage factor which has been used (1.77) means that the set of the individual gage should not exceed 11,400 micro-inches per inch minus the expected test load strain.

Since the strain measured by the strain indicator is 2.6 times the strain in one axial gage, the allowable set as measured by the strain indicator would be 29,600 micro-inches per inch minus desired test load strain. Because of the requirement for cycling before the test, this test load strain should be 2,000 micro-inches per inch, which would leave 19,400 micro-inches per inch of strain gage life from the last recorded strain indicator zero.

Unfortunately, press of time has not permitted thorough investigation of the nature of the increased strain phenomena. This was not necessary for the completion of the plate buckling project as long as it could be corrected. However, continued use of these load cells, especially when new gages have to be applied, will necessitate an investigation to insure that the linearity of the stress-strain curve remains.

2. Seven Load Cell Sensitivity Loss

After careful calibration, little difficulty was anticipated with the seven load cell electrical system. The load cells were carefully moved with the rams, while the switchboard and wiring were moved as a unit. After reassembly in the Ships Structures Laboratory, the electrical load measuring system failed to indicate a load commensurate with that shown by the hydraulic pressure gage. A plot of hydraulic pressure versus load cell strain is shown in Figure 39. The seven load cell curve dated 2/17/55 presents the calibration results while that curve dated 2/16 represents some data taken in the Ship's Structures Laboratory.

At first the usual checks for grounds, circuit correctness, and continuity were made. A small ground was discovered in one gage and that gage was replaced with no change in the results. Runs were made with each individual load cell to check the readings obtained with the

hydraulic pressure gage. A rough presentation of the locus of resulting curves is found in Figure 40. They do not exhibit the low sensitivity at low loads present in the seven load cell curve. In a very rough way they indicate considerable friction variation among the jacks as discussed in Section IV-D.

Further checks were made with groups of three load cells which showed no perceptible sensitivity loss. Considerable capacitive unbalance was found with the aid of an oscilloscope. This unbalance was minimized by using various combinations of variable capacitors in the arms of the external Wheatstone Bridge. This had no effect on the sensitivity. In addition, grounding the Baldwin strain indicator to the test frame changed the scope picture, although the poor sensitivity remained unchanged.

Since it was felt that the trouble was electrical, a precision resistor was shunted across various parts of the seven load cell circuit and results were exactly as calculated, indicating electrical reliability. Yet the pressure versus load cell strain data indicated an extremely large loss and the pressure gage checked out with the single load cells and with three load cells in series. The seven load cell circuit was then completely rewired at the load cells, eliminating the switchboard and all previously used leads. Lead length was thereby considerably shortened, but the poor sensitivity persisted.

The first concrete result was found when each load cell was shorted out one at a time. A series of seven runs were made as presented in Table IX and plotted in Figure 39. The plotted loci of curves show that the seven load cell curve dated 3/16 is some sort of an average of curves with each load cell shorted out one at a time. However, no

Figure 39
Variations in Sensitivity

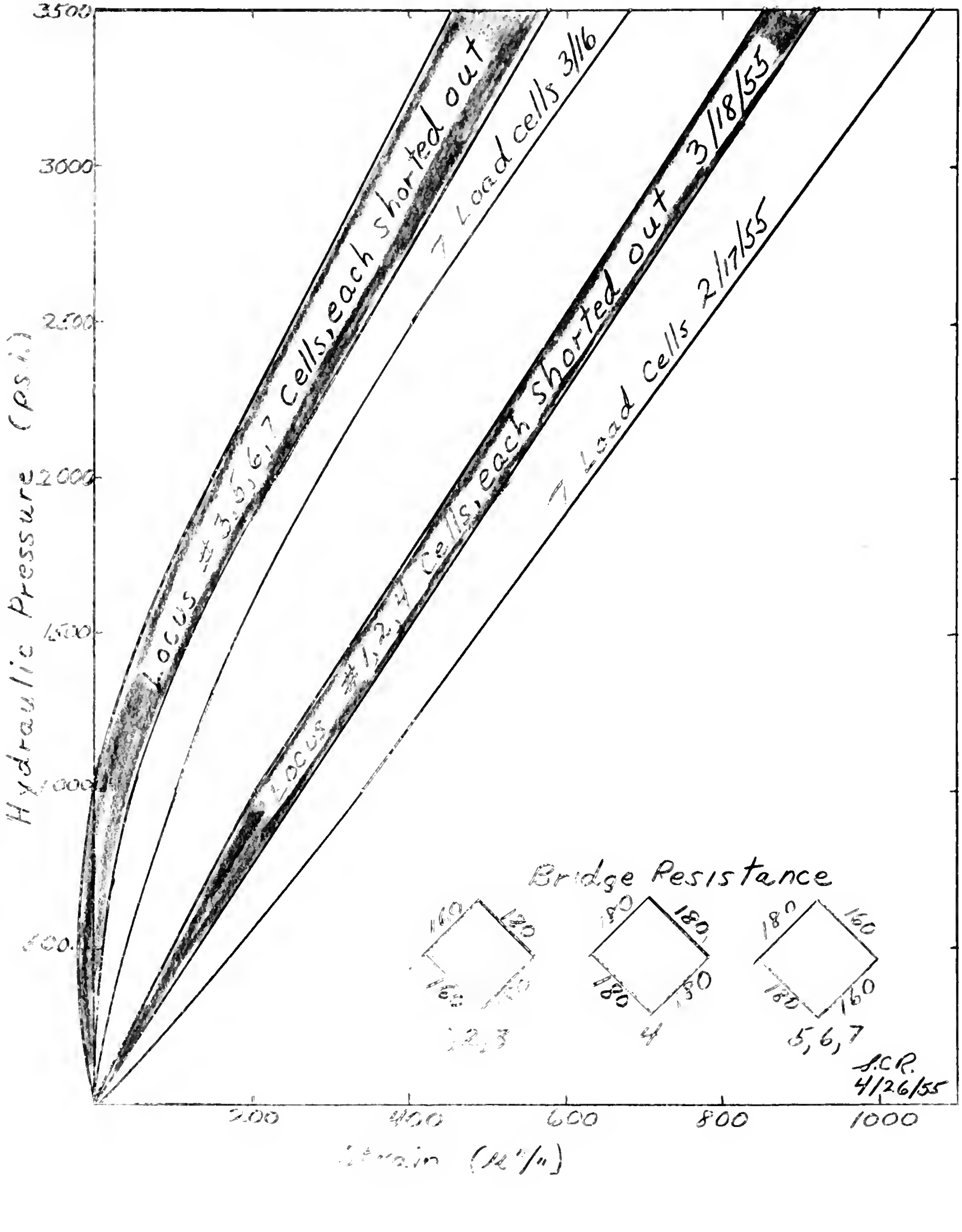
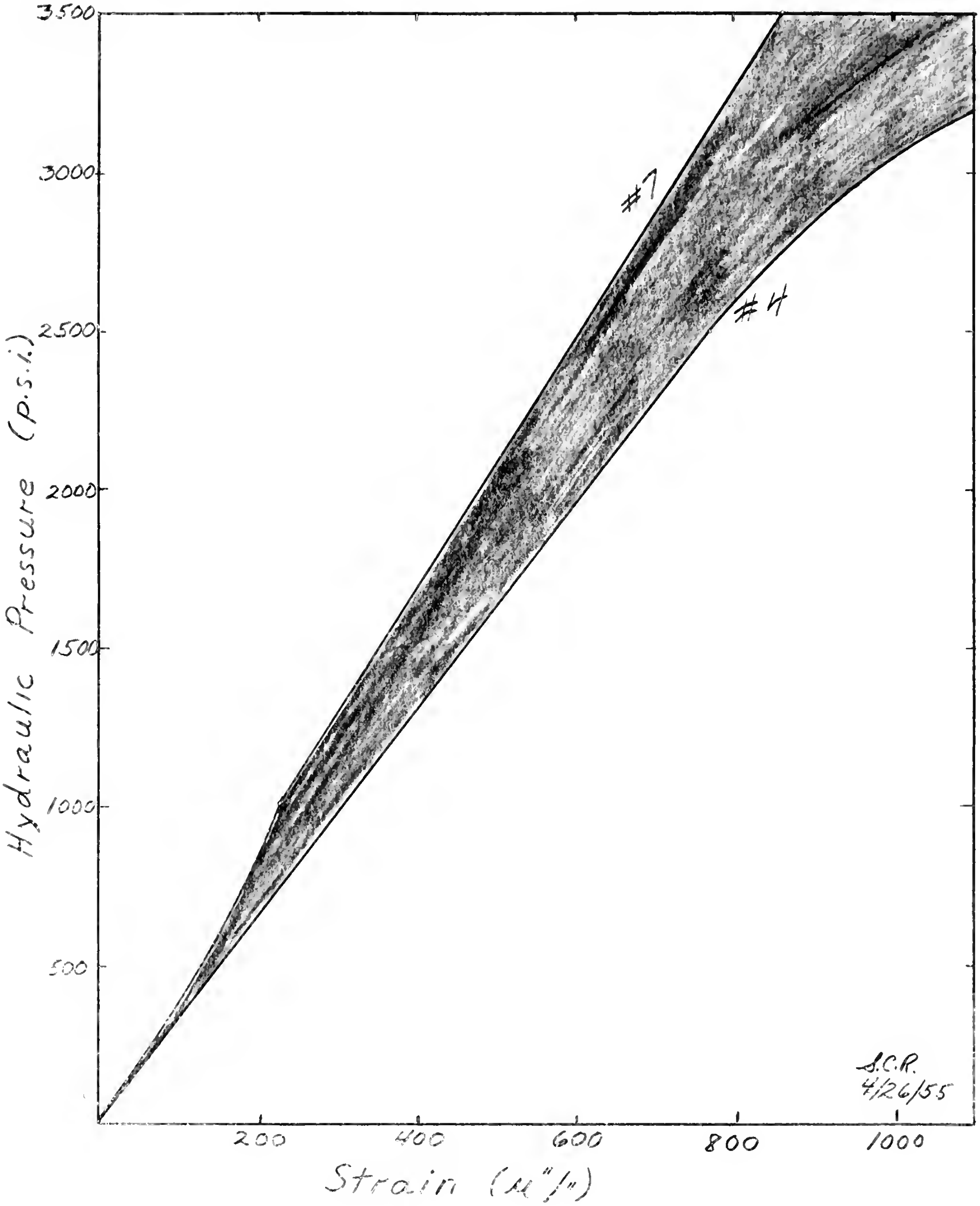


Figure 40
Load Variation Among Cells (Locus)



remedy presented itself since calibration data was not available for any six load cell combination. Accurate data was available for load cells #3, 4 and 5 in a series circuit. Because of time considerations, a compromise was made by assuming that the three center load cells on the three center rams would give a good sample of load variations among five and seven rams. Loads were measured using a 5/3 and 7/3 factor respectively for five and seven ram load application.

Difficulties with the seven load cell circuit should not have affected the three load cell circuit as has been shown. However, an element of doubt is present because the loss of sensitivity in the seven load cell circuit is unexplained. Therefore, recalibration of the three load cells applying pressure to three, five and seven rams has been recommended.

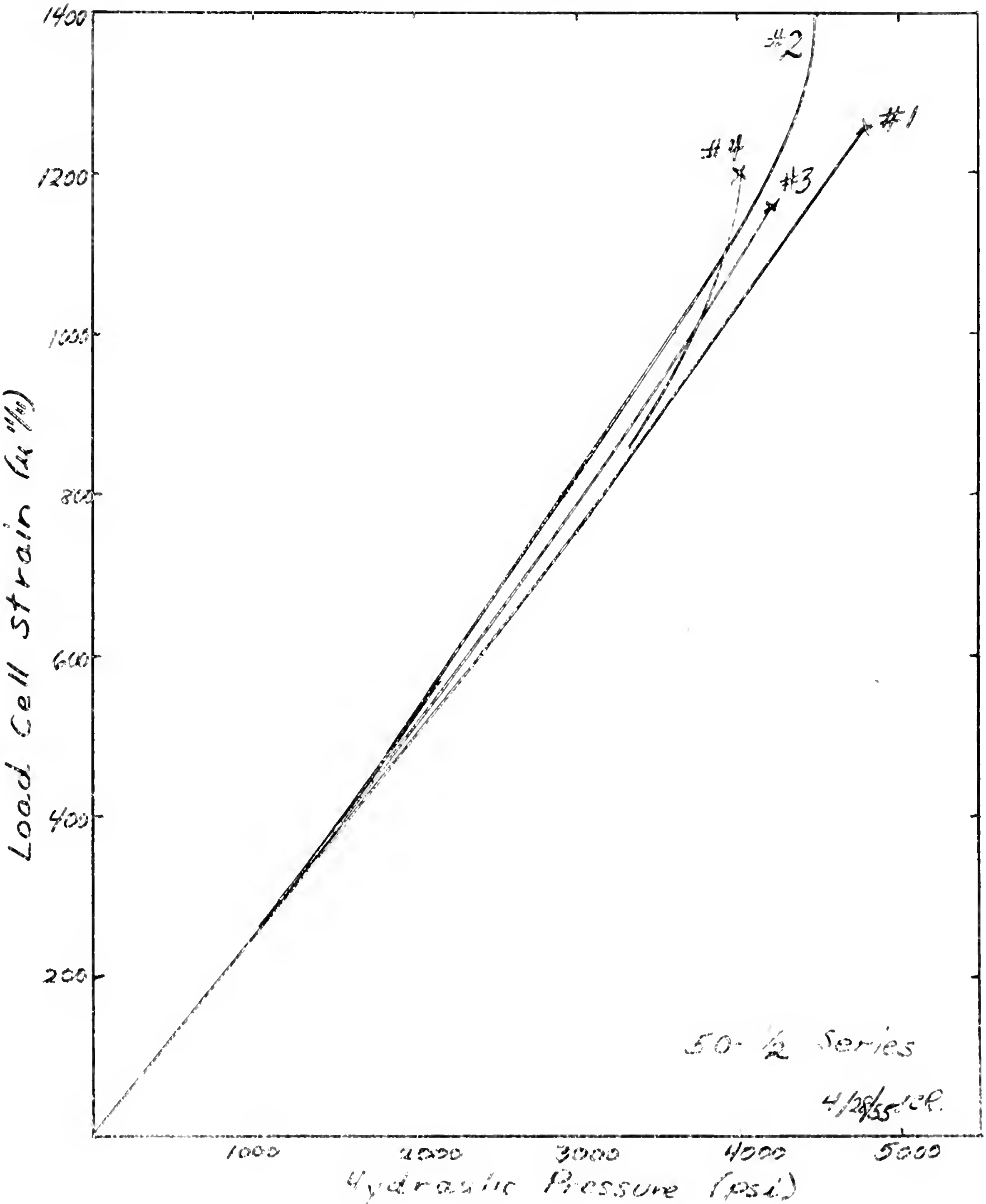
3. Load Measurement by Pressure Gage

Originally, it was believed that the hydraulic pressure gage would provide a fairly good check of the load measurement given by the load cells. In every case, a check of total hydraulic pressure against total increment of micro-inches per inch of the load cells was made before actual plate testing proceeded. The pressure gage proved useful for this purpose but did not provide a good check during plate buckling tests. Figure 41 shows the results of plotting hydraulic pressure against load cell increment for series 50-1/2.

In this plot, there can be seen, at high loads, a falling off of measured hydraulic pressure with increasing load as measured by the load cells. The only difference between the cycling piece and the test plate is that the plate is yielding, causing the rams to extend and oil to flow. This oil flow past the pressure gage tap is always present at

higher loads when leakage is more pronounced. However, the increased flow caused by the yielding plate must produce an increasing Bernoulli effect such that the pressure felt by the moving rams is not that measured by the oil pressure gage. For this reason, it is recommended that no reliance be placed on the oil pressure gage for plate buckling data except as a gross check that the machine is not overloaded.

Figure 41
Bernoulli Effect



F. YOUNG'S MODULUS AND PROPORTIONAL LIMIT

The same compression jig used by Pittman and Rinehart [5] was employed to determine the modulus of elasticity and proportional limit for two additional thicknesses.

Briefly, the compression jig consists of a frame which contains grooved guide plates and a plunger-type subpress. The grooved guide plates provide stability for the specimen and yet allow lateral strain. Two Huggenberger tensometers of one inch gage length are mounted on opposite sides to measure strain parallel to the applied load. (See [3] for Huggenberger tensometer operation). The load is applied to the plunger by a suitable loading machine through a hemisphere to reduce unequal loadings and friction effects.

The specimens were cut from the same plate and in the same direction as were the test plates. Surface preparation included additional cleaning with abrasives which removed almost all pitting, leaving uniform thickness of clearly effective material.

Tests for plate of 7/32" thickness for the "50" series were carried out by Gaucher and Rinehart on July 1, 1954. Tests for plate of 1/4" thickness for the "40" series were carried out by the authors on April 28, 1955. Results are presented in Figures 42 and 43.

For the 1/4" thickness, the first specimen gave a modulus of 38 million. Subsequent check of the strain gages revealed faulty technique in that zero settings had been set by forcing probe points, thus reducing sensitivity in the microscopically scratched area. Three subsequent specimens were successfully tested giving easily comparable and creditable results for the modulus of elasticity. Proportional limit results were somewhat more scattered but averaged well. Behavior of number three

specimen indicates gage slippage above 15,000 psi. and the possible over-restriction of lateral expansion by the grooved guide plates being set too tightly.

For the 7/32" thickness, three specimens were tested. The data from number one specimen does not appear to be reliable since the modulus is large. Therefore, values from this specimen were disregarded. Number two specimen gave a high proportional limit above 30,000 psi. It is to be suspected that gage slippage is again the cause although points plotted consistently indicating slippage was smooth, if present. Number three specimen was the best giving the characteristic stress-strain curve of steel, although the test was not carried out to high loadings. The proportional limit indicated was low however, and rather than assume an average between widely separated values, a proportional limit of 25,000 psi. was assumed for 7/32" thickness.

The moduli of elasticity and proportional limits for the three thicknesses are listed below.

Thickness (in.)	E (psi)	prop. (psi)
5/32	28,300,000*	25,000**
7/32	30,200,000	25,000**
1/4	30,200,000	25,200

The moduli of elasticity were used to determine theoretical buckling critical stresses for comparison with actual results. The proportional limits were used merely as an aid in analysing the bending and average stress curves for the buckled plates.

* From Pittman and Rinehart [5] since their specimens came from the same plate as all the "70" series.

** Published values because of poor or insufficient experimental results [4].

Figure 42
Determination of Modulus of Elasticity
Stress vs Strain
(t = 7/32")

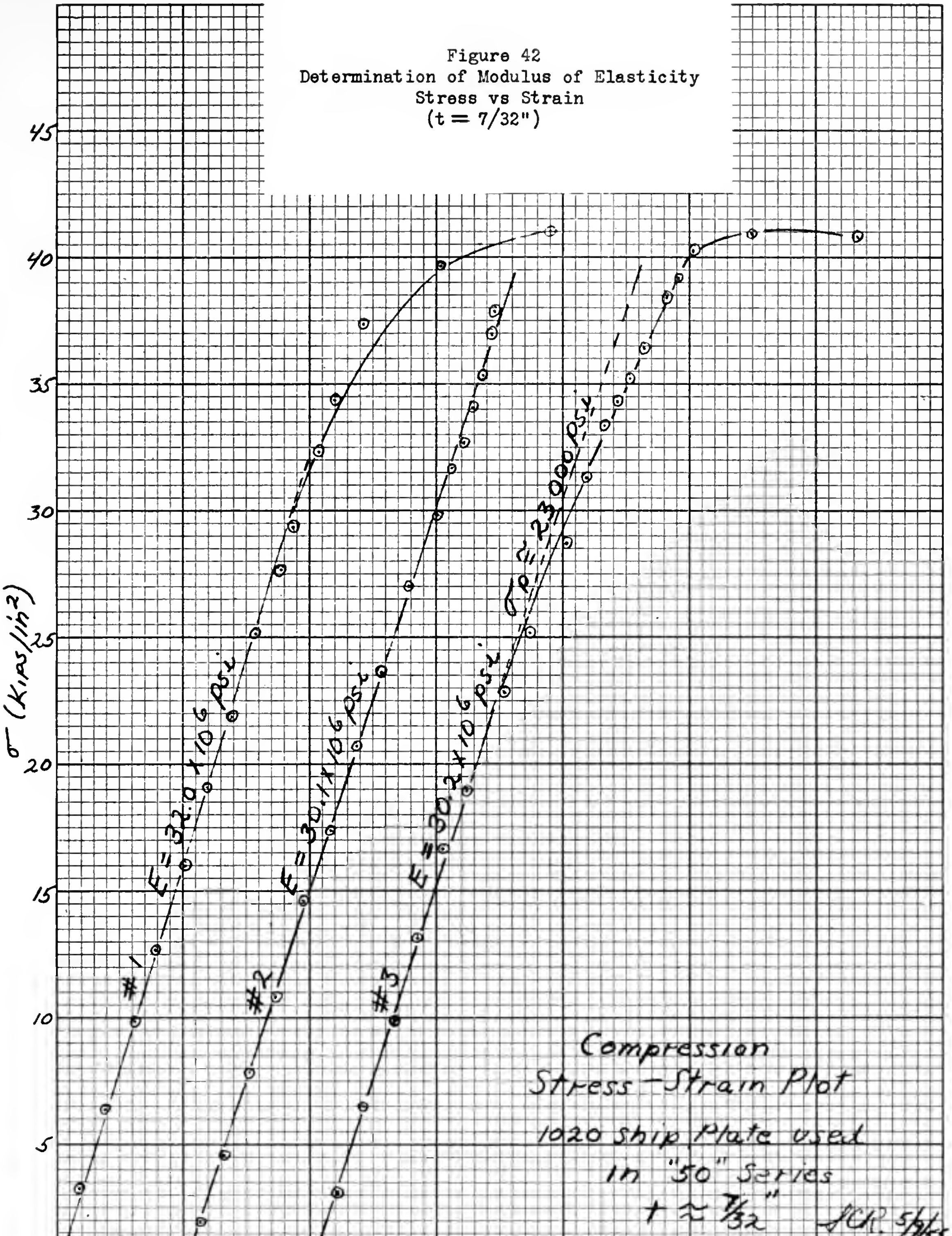
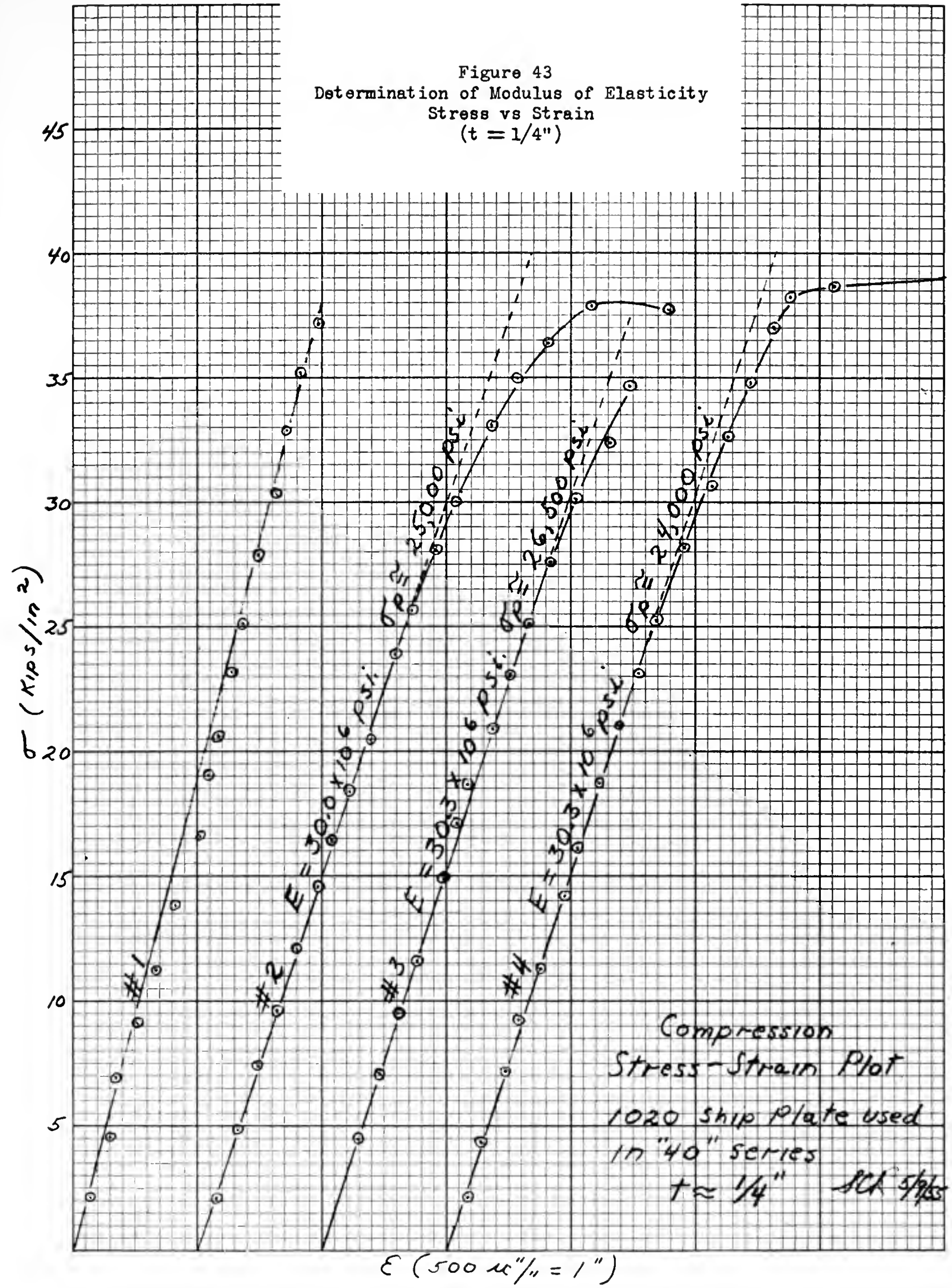


Figure 43
Determination of Modulus of Elasticity
Stress vs Strain
(t = 1/4")



G. ORIGINAL DATA

TABLE V-A

Calibration Test
Seven Load Cells

Run #1
Temp. 79°F.

Strain Indicator:
Baldwin Type-L, #H59241
G.F. = 1.77
Gage: Blackhawk Z-720

12 February 1955
Standard:
300,000# test machine
M.I.T. #105
Complete Switchboard

Load (lbs.)	Load Indicator (μ-in/in)	Pressure (psig)
0	0-6-1148	
19,000	1297	
40,000	1425	
60,000	1565	1700
80,000	1731	
100,500	1912	2700
120,000	0-8-0103	
140,000	0337	3900
160,000	0628	4200
200,000	1483	
180,000	1341	
170,000	1263	
150,000	1106	
130,000	954	
110,000	800	
90,000	647	
70,000	490	
50,000	338	
30,000	198	
10,000	054	
0	0-6-1950	

TABLE V-B

Calibration Test
Seven Load Cells

Run #2
Temp. 75°F.

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77
Gage: Blackhawk Z-720

14 February 1955
300,000# test machine
M.I.T. #105
Complete Switchboard

Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)	Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)
.6	0-6-1912	0	210.0	1608	5700
10.0	1978	250	200.0	1531	5410
20.0	0-8-0040	480	190.0	1457	5140
29.9	0113	760	180.0	0-8-1380	4880
40.0	0190	1100	170.0	1302	4600
50.0	0263	1350	160.0	1225	4300
60.0	0338	1600	150.0	1146	4050
69.6	0412	1870	140.0	1070	3800
80.0	0491	2200	130.0	0995	3470
90.0	0565	2400	120.0	0921	3250
100.0	0639	2700	110.0	0842	2950
110.0	0716	3000	100.0	0767	2700
120.0	0789	3250	90.0	0693	2450
130.0	0864	3510	80.0	0616	2150
140.0	0943	3800	70.0	0528	1850
150.0	1018	4050	60.0	0462	1580
160.0	1096	4350	50.0	0386	1300
170.0	1179	4670	40.0	0310	1040
180.0	1260	4910	29.9	0232	750
190.0	1348	5200	20.0	0167	450
200.0	1442	5450	10.0	0105	220
210.0	1557	5700	.6	0-8-0023	0
220.0	1679	6000			

TABLE V-C

Calibration Test
Seven Load Cells

Run #3

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77
Gage: Blackhawk Z-720

16 February 1955
300,000# test machine
M.I.T. #105
Switchboard: complete

Note: Blackhawk P-182 in system but not applying load.

Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)
(30 kip gage)		
0	0-8-0129	0
2.0	0153	-
4.0	0178	80
6.0	0201	110
8.0	0221	160
10.0	0242	200
12.0	0261	250
14.0	0281	310
16.0	0298	370
18.0	0317	410
20.0	0333	480
22.0	0352	510
24.0	0367	580
26.0	0386	620
28.0	0402	700
(150 kip gage*)		
30.0	0-8-0419	770
35.0	0461	900

Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)
40.0	0502	1040
45.0	0546	1200
50.0	0584	1310
55.0	0-8-0628	1480
60.0	0667	1600
65.0	0707	1730
70.0	0747	1900
80.0	0826	2180
90.0	0904	2430
100.0	0982	2700
110.0	1062	2980
120.0	1142	3260
130.0	1224	3500
140.0	1305	3800
(300 kip gage**)		
150.0	0-8-1386	4060
160.0	1468	4300
gage cut-out value blew out of 150 kip system		
0	0-8-0168	0

* 150 kip gage matched to 30 kip gage at 28 kip load.
** 300 kip gage matched to 150 kip gage at 140 kip load.

TABLE V-D

Calibration Test
Seven Load Cells

Run #4

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77
Gage: Blackhawk Z-720

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: complete

Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)
(30 kip gage)		
0	0- 8-0152	0
5	0218	100
10	0273	200
15	0323	320
20	0370	480
25	0417	-
29	0452	710
(150 kip gage)*		
35	0-8 -0503	900
40	0546	1020
45	0589	1200
50	0630	1310
55	0676	1470
60	0717	1600
65	1756	1730
70	0798	1900
75	0837	2010
80	0879	2180
90	0959	2440
100	1036	2700
110	0-8 -1117	2980
120	1198	3260
130	1279	3500
140	1363	3800
(300 kip gage)**		
150	0-8 -1451	4060
160	1542	4310
170	1630	4610
180	1722	4900
190	1818	5130
200	1915	5420
210	0-10-0022	5700
220	0122	5970

Load (KIPS)	Load Indicator (μ-in/in)	Pressure (psig)
210	0053	5700
200	0-8-1973	5430
190	1898	
180	1823	4900
160	1664	
150	1586	
140	1510	
130	1429	
120	0-8-1352	
100	1197	2700
90	1119	
80	1039	
70	0958	1950
60	0880	
50	0793	
40	0711	
30	0627	
20	0-8-0538	
15	0490	
10	0441	
8	0421	
6	0402	
4	0377	
2	0352	
1	0341	
0	0-8-0327	

* 150 kip gage matched to 30 kip gage at 29 kip load.
** 300 kip gage matched to 150 kip gage at 140 kip load.

TABLE V-E

Calibration Test
Seven Load Cells

300 kip gage used throughout

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: complete

Load (KIPS)	Run #5 Load Indicator (μ-in/in)	Run #6 Load Indicator (μ-in/in)	Run #7 Load Indicator (μ-in/in)	Run #8 Load Indicator (μ-in/in)	Run #9 Load Indicator (μ-in/in)
0	0- 8-0323	0- 8-0346	0- 8-0378	0- 8-0341	0- 8-0360
10	0436	0455	0487	0458	0475
20	0523	0542	0572	0547	0563
30	0607	0627	0655	0632	0647
40	0692	0711	0740	0719	0732
50	0771	0791	0819	0798	0811
60	0851	0870	0898	0880	0892
70	0929	0948	0979	0962	0974
80	1010	1030	1058	1041	1054
90	1089	1108	1136	1119	1133
100	1165	1183	1212	1198	1208
110	1242	1261	1289	1274	1286
120	1322	1342	1368	1358	1367
130	1398	1417	1446	1432	1444
140	1478	1498	1526	1514	1523
150	1553	1572	1599	1589	1599
160	1634	1654	1683	1672	1681
170	1713	1731	1761	1749	1758
180	1790	1812	1839	1829	1837
190	1871	1890	1919	1908	1917
200	1951	1969	1998	1987	1993
210	0-10-0033	0-10-0055	0-10-0081	0-10-0071	0-10-0076
220	0123	0144	0169	0156	0157
150	-	0- 8-1601	0-8 -1618	0- 8-1612	0- 8-1613
100	-	1216	1232	1224	1224
50		0821	0832	0826	0828
0	0- 8-0346	0- 8-0366	0- 8-0377	0- 8-0361	0- 8-0366

TABLE V-F

Calibration Test
Seven Load Cells

Miscellaneous Runs

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: complete

Load Gage:
Short Runs

Load (KIPS)	Run I Load Indicator (μ-in/in)	Run II Load Indicator (μ-in/in)
0	0-8-0362	0-8-0365
3	0402	0403
5	0427	0427
10	0477	0479
15	0522	0527
20	0567	0571
25	0611	0615
30	0653	0658
20	0567	-
10	0476	-
0	0-8-0364	0-8-0365

Load Gage: 300 kip
Long Runs

Load (KIPS)	Run III Load Indicator (μ-in/in)	Run IV Load Indicator (μ-in/in)	Run V Load Indicator (μ-in/in)
0	0-8-0366	0-8-0366	0-8-0367
50	0818	-	-
100	1213	1215	1217
150	1605	-**	-
150*	1604	-	-
100	1219	-	-
50	0825	-	-
0	0-8-0366	0-8-0367	0-8-0367

* Load increased to 155 kips before reducing load.
** Maximum load for Runs IV and V is 100 kips.

TABLE V-G

Calibration Test
Seven Load Cells

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: complete

Note: Conducted after 3-cell calibration.

7-cell check

Load (KIPS)	Load Indicator (μ-in/in)
0	0-8-0467
10	0579
20	0676
30	0764
40	0852
50	0936
60	1017
70	1098
80	1182
90	1262
100	1344
110	1421
120	1502
130	1583
140	1665
150	1742
160	1827
170	1912
180	1999
190	0-10-0102
200	0213
210	0336
220	0495
0	0- 8-0673

High Load Cycling

Load (KIPS)	Load Indicator (μ-in/in)
0	0- 8-0673
220	0-10-0539
0	0- 8-0722
220	0-10-0552
0	0- 8-0745
220	0- 8-0556
0	0- 8-0765
(Final Run)	
0	0- 8-0765
10	0867
20	0952
30	1034
50	1197
100	1596
150	1987
180	0-10-0231
190	0309
200	1389
210	0473
220	0566
0	0- 8-0781

TABLE VI-A

Calibration Test
Three Load Cells

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77
Load Gage: 150 gage

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: partial

Note: Switchboard leads #5, 6, 7 connected to cells #3, 4, 5 respectively. Switches 3a, 3a', 3t, and 3t' open; switches 4a and 4t' shorted. Runs #3, 4, 5 only applying the load.

Preliminary Runs

Load (KIPS)	Run #1 Load Indicator (μ-in/in)	Run #2 Load Indicator (μ-in/in)	Run #3 Load Indicator (μ-in/in)
0	0- 8-0709	0- 8-0777	0- 8-0282
5	0797	-	-
10	0882	-	-
20	1058	-	-
30	1237	-	-
40	1412	-	-
50	1592	-	-
60	1777	-	-
70	1956	0-10-0023	0-10-0076
80	0-10-0147	0201	0255
90	0362	0391	0433
95	-	0513	0527
50	0- 8-1661	-	-
0	0- 8-0776	0- 8-0828	0- 8-0841

TABLE VI-B

Calibration Test
Three Load Cells

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77
Load Gage: 150 kip

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: partial

Note: Conditions same as note of Table VI-A.

Load (KIPS)	Run #4 Load Indicator (μ-in/in)	Run #5 Load Indicator (μ-in/in)	Run #6 Load Indicator (μ-in/in)
0	0- 8-0864	0- 8-0871	0- 8-0877
5	0957	0962	0956
10	1042	1048	1053
20	1218	1222	1227
30	1396	1402	1407
40	1573	1581	1583
50	1752	1760	1762
60	1933	1943	1947
70	0-10-0109	0-10-0109	0-10-0122
80	0287	0298	0298
90	0470	0476	0479
95	0560	0565	0568
50	0- 8-1768	-	-
0	0- 8-0871	0- 8-0877	0- 8-0880

TABLE VI-C

Calibration Test
Three Load Cells

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 1.77

17 February 1955
300,000# test machine
M.I.T. #105
Switchboard: partial

Note: Same conditions as in note of Table VI-A.

Load Gage: 150 kip
Check on Data Spread

Load (KIPS)	Load Indicator (μ-in/in)
0	0-8-0880
50	1766
0	0-8-0880
50	1771
0	0-8-0880
50	1767
0	0-8-0880

Load Gage: 30 kip
Check on low ranges

Load (KIPS)	Load Indicator (μ-in/in)
0	0-8-0880
2	0920
4	0955
5	0972
0	0-8-0882
2	0920
4	0954
5	0972
0	0-8-0882

TABLE VII

Effect of Loading Conditions on Number 1 Load Cell

Strain Indicator:
Baldwin Type-L, #H59241
G.F.: 2.02

15 February 1955
10,000# test machine
M.I.T. #202

Load Cell:
1. Four gages in four arm bridge
2. Cupped end fitted loosely over solid bar
3. Other end against side of 1" rod or against flat base

With 1" rod		Without 1" rod	
Load lbs.	Strain μ-in/in	Load lbs.	Strain μ-in/in
0	0-6-1095	1186	0-6-1153
2026	1187	6000	1383
4010	1277	8002	1476
5986	1373	10,006	1568
8010	1470	1186	1148
1060	1568		
0	1093		

TABLE VIII

Load Variation Among Individual Cells

Strain Indicator:
Baldwin Type L, #H59241
G.F.: 1.77

14 February 1955
300,000# test machine
M.I.T. #105
Switchboard:
Individual cells

Note: All readings taken while load was maintained at 100,000 lbs. ± 1000 lbs.

Load Cell #	Load Indicator @ zero Load (μ-in/in)	Load Indicator @ 100,000# (μ-in/in)	Load Indicator @ zero Load (μ-in/in)
1	0-6-0585	0-6-1320	0-6-0585
2	8-1508	10-0310	8-1539
3	8-0507	8-1240	8-0502
4	8-0841	8-1608	8-0848
5	6-1845	8-0612	6-1820
6	6-1183	6-1930	6-1180
7	8-0837	8-1540	8-0808

Pressure gage:
Z-720 Blackhawk

18 March 1955
All seven rams applying Load, Bldg. #41

	Pressure (psi)	Load Indicator (μ-in/in)		Pressure (psi)	Load Indicator (μ-in/in)
#1 Load Cell	0	0-6-0970	#2 Load cell	0	0-10-1417
	500	1091		500	1556
	1000	1221		1000	1694
	1500	1341		1500	1833
	2000	1465		2000	1970
	2500	1600		2500	2120
	3000	1726		3000	2252
	0	0-6-0968		0	0-10-1415
#3 Load cell	0	0-8-0950	#4 Load cell	0	0-10-1670
	500	1092		500	1823
	1000	1214		1000	1972
	1500	1350		1500	0-12-0130
	2000	1488		2000	281
	2500	1611		2500	458
	3000	1748		3000	674
	0	0-8-0949		0	0-10-1688

TABLE VIII (continued)

Load Variation Among Individual Cells

	Pressure (psi)	Load Indicator (μ-in/in)		Pressure (psi)	Load Indicator (μ-in/in)
#5 Load cell	0	0-8-0019	#6 Load cell	0	0-8-0548
	500	160		500	683
	1000	288		1000	802
	1500	412		1500	932
	2000	531		2000	1053
	2500	654		2500	1182
	3000	820		3000	1320
	0	0-8-0045		0	0-8-0548
#7 Load cell	0	0-10-0631			
	500	752			
	1000	855			
	1500	980			
	2000	1107			
	2500	1234			
	3000	1361			
	0	C-10-0632			

TABLE IX

Sensitivity of Load Cells After Moving

Strain Indicator:
Baldwin Type L, #H59241
G.F.: 1.77
Switchboard: Seven load cells connected except as noted

Seven Rams applying Load - Building 41

Pressure Gage:
Z-720 Blackhawk

	Pressure (psi)	Load Indicator (μ-in/in)
All Load cells 3/11/55	0	0-8-0693
	500	732
	1000	797
	1500	881
	2000	978
	2500	1092
	2700	1145
	5000	1858
#1 Load cell shorted at switchboard 3/18/55	0	0-8-1628
	500	1755
	1000	1864
	1500	1982
	2500	0-10-0250
	3000	352
	3500	486
	4000	614
#2 Load cell shorted at switchboard 3/18/55	0	0-8-0888
	500	992
	1000	1094
	1500	1221
	2000	1350
	0	0-8-0888

	Pressure (psi)	Load Indicator (μ-in/in)
#3 Load cell shorted at switchboard 3/18/55	0	0-8-1201
	500	1218
	1000	1250
	1500	1328
	2000	1430
	2500	1544
	0	0-8-1208
#4 Load cell shorted at switchboard 3/18/55	0	0-8-1173
	500	1306
	1000	1432
	1500	1561
	2000	1686
	2500	1828
	3000	1953
	3500	0-10-0098
	0	0- 8-1172
#5 Load cell shorted at switchboard 3/18/55	0	0- 8-1290
	500	1285
	1000	1315
	1500	1385
	2000	1468
	2500	1568
	3000	1679
	0	0-8-1289

TABLE IX (Continued)

Sensitivity of Load Cells After Moving

	Pressure (psi)	Load Indicator (μ-in/in)		Pressure (psi)	Load Indicator (μ-in/in)
	0	0-8-1291		0	0-10-1618
#6 Load cell shorted at switchboard 3/18/55	400	1271	#3,4,5 load cells to switches 5,6,7 0930, 3/24/55	500	1758
	500	1272		1000	1887
	1000	1291		1500	0-12-0021
	1500	1362		2000	149
	2000	1443		2500	288
	2500	1541		3000	426
	3000	1648		3500	571
	0	0-8-1287		4000	709
				4500	851
	0	0-8-0652		5000	1000
#7 Load cell shorted at switchboard 3/18/55	250	642		5500	1150
	500	646		6000	1302
	1000	677		0	0-10-1660
	1500	748			
	2000	820			
	2500	914			
	3000	1012			
	3500	1124			
	4000	1246			
	0	0-8-0648			

TABLE X

Effect of Time on Load Cell Creep

Strain Indicator:
  Baldwin Type L, #H59241
  G.F.: 1.77
Switchboard: Load cells 3,4,5
  to switches 5,6,& 7 in series.

23-24 March 1955
Seven rams applying
load, Building #41
Pressure gage:
  Z-720 Blackhawk

		Pressure (psi)	Load Indicator (μ-in/in)
		0	0-10-1554
1030	3/23/55	6000	0-12-1277
		0	0-10-1599
		0	0-10-1591
1630	3/23/55	6000	0-12-1282
		0	0-10-1610
		0	0-10-1600
0915	3/24/55	6000	0-12-1292
		0	0-10-1628
		0	0-10-1618
0930	3/24/55	6000	0-12-1302
0932		6000	0-12-1332
		0	0-10-1660
		0	0-10-1656
0955	3/24/55	5000	0-12-1040
1001		5000	0-12-1040
		0	0-10-1662

TABLE XI-A

Data Sheet

PL 40-1/4-1
a: 10.188"
b: 43.750"
t: .268"
pits: .018"
% area: 60
unfairness:
none
concave down

Strain Indicators: (Baldwin)
Load Meas: Type L, H59241
G.F.: 1.77
PL Gages: Type K, D-58115
G.F.: 2.00
Press. Gage: Blackhawk Z-720
Micrometer: Starrett #436(1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

24 March 1955
Ship Structures Lab
Bldg. 41, M.I.T.
Load applied: 7 jacks
Center sling used
Solder set @ 1000 psi.
Segments spaced 1/4"

Run #1

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage #5 (μ-in/in)	Bottom Gage #6 (μ-in/in)
0-10-1673	0	0-1-1531	0-4-0657
1700	100	1522	0647
1750	260	1501	0627
1800	440	1481	0608
1850	630	1458	0586
1900	830	1438	0567
1950	1020	1417	0546
2000	1220	1396	0527
0-12-0050	1410	1372	0508
0100	1600	1348	0487
0150	1800	1326	0469
0200	1990	1300	0453
0250	2190	1278	0437
0300	2380	1252	0421
0350	2510	1228	0407
0400	2700	1203	0395
0450	2900	1175	0382
0475	2990	1161	0375
0500	3080	1148	0370
0525	3170	1132	0363
0550	3250	1118	0358
0575	3320	1103	0353
0600	3410	1083	0350
0625	3510	1065	0349
0650	3610	1044	0347
0675	3700	1023	0347
0700	3800	1001	0349
0725	3900	0977	0352
0750	3980	0953	0358
0775	4050	0926	0365
0800	4130	0898	0373

Run #1 (continued)

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage #5 (μ-in/in)	Bottom Gage #6 (μ-in/in)
0-12-0825	4200	0-1-0869	0-4-0383
0850	4300	0840	0389
0875	4410	0802	0405
0900	4500	0758	0430
0925	4550	0728	0446
0950	4600	0682	0471
0975	4700	0635	0500
1000	4760	0589	0528
1025	4830	0532	0567
1050	4900	0472	0611
1075	4970	0392	0665
1100	5040	0309	0715
1125		pump overheated	
0-10-1722	0	0-1-1547	0-4-0644

TABLE XI-B

Data Sheet

PL 40-1/4-1 a: 10.188" b: 43.750" t: .268" pits: .018" % area: 60. unfairness: none concave down	Strain Indicators: (Baldwin) Load Meas: Type L, H59241. G.F.: 1.77 PL Gages: top-type L, H80797 bottom-type K, D-43238 G.F.: 2.00 Pressure Gage: Blackhawk Z-720 Micrometer: Starrett #436(1") Dial Indicator: Ames 88 (1" @ .001") 5" extension	25 March 1955 Ship Structures Lab. Bldg. 41, M.I.T. Load Applied: 7 jacks Center sling used Ball Bg. Shims: top Segments spaced 1/4"

Run #2

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-10-1703	0	0-14-1115	0-4-0435
1800	0320	1085	0412
1900	0710	1042	0382
2000	1090	0992	0348
0-12-0100	1490	0942	0320
0200	1900	0882	0292
0300	2280	0821	0271
0400	2610	0753	0255
0500	2980	0678	0245
0600	3350	0588	0244
0650	3510	0541	0244
0700	3650	0486	0253
0750	3900	0427	0268
0800	4100	0363	0286
0850	4280	0293	0315
0900	4300	0211	0354
0950	4650	0099	0418
1000	4810	0-12-1955	0490
1050	5010	1788	0632
1100	5180	1417	0966
1150	plate buckled downward, loud noise		
1703	0	strain gages broken	

TABLE XI-C

Data Sheet

PL: 40-1/4-2	Strain Indicators: (Baldwin)	26 March 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 43.750"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .262"	PL Gages: top - type K, D58110	Load Applied: 7 jacks
pits: .020"	bottom - type L, H80797	Center Sling used
% area: 50	G.F.: 2.03	Solder set @ 1100 psi.
unfairness:	Pressure Gage: Blackhawk Z-720	Ball Bg. Shim - under
a: fair	Micrometer: Starrett #436 (1")	Segments spaced 1/4"
b: 1/32"	Dial Indicator: Ames 88	
Concave down	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-10-1735	0	0-8-1163	0-6-0371
1800	210	1142	0333
1900	610	1113	0282
2000	1000	1086	0226
0-12-0100	1380	1063	0169*
0200	1750	1043	0105
0300	2160	1022	0038
0400	2490	1013	0-4-1959
0500	2880	1011	1873
0600	3240	1024	1779
0650	3400	1037	1726
0700	3520	1052	1662
0750	3780	1075	1597
0800	3960	1111	1513
0850	4130	1171	1403
0900	4300	1237	1298
0950	4500	1357	1133
1000	4700	1525	0930
1050	4890	1912	0521
1075	buckled upward, concave down		
0-10-1680	0		

* sling removed

TABLE XI-D

Data Sheet

PL: 40-1/4-3
a: 10.188"
b: 43.750"
t: .264"
pits: .011"
% area: 50
unfairness:
none

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top - type K, D58110
bottom - type L, H80797
G.F.: 2.00
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

26 March 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 7 jacks
Solder Set @ 500 psi.
Ball Bg. Shims - top
Segments spaced 1/4"

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-10-1675	0	0-8-1882	0-8-1963
1700	90	1874	1948
1800	440	1847	1903
1900	830	1820	1852
2000	1220	1792	1803
0-12-0100	1590	1765	1751
0200	2000	1746	1692
0300	2390	1733	1633*
0400	2750	1725	1562
0500	3040	1722	1485
0550	3300	1722	1439
0600	3470	1729	1392
0650	3670	1737	1337
0700	3800	1753	1278
0750	4000	1776	1218
0800	4170	1808	1143
0850	4300	1843	1067
0900	4480	1891	0988
0950	4610	1947	0900
1000	4750	0-9-1012	0803
1025	4800	1045	0763
1050	4820	1082	0718
1075	4910	1127	0659
1100	4930	1175	0602
1125	4990	1235	0535
1150	5080	1305	0448
1175	5130	1406	0335
1200	5170	1507	0222
1225	5230	1686	0025
1240	buckled upward		
1755	0		

* centered up with noise.

TABLE XI-E

Data Sheet

PL 40-1/4-4
a: 10.188"
b: 43.750"
t: .258"
pits: .009"
% area: 40.
Unfairness:
none

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top - type K, D58110
bottom - type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

29 March 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 7 jacks
Solder set @ 350 psi.
Segments spaced 1/4"

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-10-1888	0	A-4-0979	0-12-0161
1900	-	0978	0159
2000	390	0956	0106
0-12-0100	770	0939	0048
0200	1170	0931	0-10-1975
0300	1550	0931	1899
0400	1970	0942	1811
0500	2310	0967	1709
0550	2500	0983	1651
0600	2700	1008	1587
0650	2900	1038	1512
0700	3090	1078	1433
0750	3270	1125	1348
0800	3450	1183	1252
0850	3620	1262	1138
0900	3820	1373	1005
0950	4000	1512	0839
1000	4150	1688	0645
1050	4230	1925	0405
1085	buckled upward, concave down		
1882	0		

TABLE XII

Data Sheet

PL 50-1/4-4
a: 10.188"
b: 43.750"
t: .222"
pits:
T-.004";B-.010"
% area: 30; 10
Unfairness:
a: fair
b: 1/8"
Concave down

Strain Indicators: (Baldwin)
Load Meas: Type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58110
bottom-type L, H80797
G.F.: 2.03
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

29 March 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 7 jacks
Solder set @ 500 psi.
Segments spaced 1/4"

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-10-1889	0	A-3-1112	0-10-0538
1950	220	1107	0493
2000	400	1103	0456
0-12-0100	800	1107	0373
0150	1000	1113	0323
0200	1190	1124	0268
0250	1370	1139	0208
0275	1470	1153	0173
0300	1550	1165	0138
0325	1640	1182	0099
0350	1760	1202	0056
0375	1840	1225	0011
0400	1930	1256	0-8-1956
0425	2070	1288	1897
0450	2130	1335	1832
0475	2240	1382	1766
0500	2350	1438	1683
0525	2440	1508	1592
0550	2550	1612	1459
0575	2600	1722	1335
0600	2700	1846	1189
0625	2800	A-4-1038	0993
0650	2900	A-4-1501	0-8-0532
0-12-0660	-	buckled up,	concave down
0-10-1879	0		

TABLE XIII-A

Data Sheet

PL 50-1/3-1
a: 10.188"
b: 32.813"
t: .226"
pits:
T-.004"; B-.015"
% area: 30; 50.
Unfairness:
a: none
b: 3/16"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D43238
bottom-type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

1 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 cells
Solder set @ 400 psi.

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-12-0770	0	0-5-0012	0-10-1052
0800	110	0005	1031*
0900	500	0905	0975
1000	900	0867	0931
1100	1270	0828	0879
1200	1610	0797	0821
1300	2000	0762	0761
1400	2390	0736	0697
1450	2510	0725	0661
1500	2710	0721	0622
1550	2890	0722	0582
1600	3070	0731	0529
1650	3210	0752	0466
1700	3390	0788	0381
1750	3500	0855	0272
1775	3610	0893	0211
1800	3700	0958	0128
1825	3780	1067	0006
1850	3870	1138	0-8-1903
1875	3920	1278	1754
1900	-	1522	1492
1925	-	1935	1086
1930	buckled up - concave down		
0702	0		

* no center sling

TABLE XIII-A

Data Sheet

PL 50-1/3-1
a: 10.188"
b: 32.813"
t: .226"
pits:
T-.004";B-.015"
% area: 30; 50.
Unfairness:
a: none
b: 3/16"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D43238
bottom-type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

1 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 cells
Solder set @ 400 psi.

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-12-0770	0	0-5-0012	0-10-1052
0800	110	0005	1031*
0900	500	0905	0975
1000	900	0867	0931
1100	1270	0828	0879
1200	1610	0797	0821
1300	2000	0762	0761
1400	2390	0736	0697
1450	2510	0725	0661
1500	2710	0721	0622
1550	2890	0722	0582
1600	3070	0731	0529
1650	3210	0752	0466
1700	3390	0788	0381
1750	3500	0855	0272
1775	3610	0893	0211
1800	3700	0958	0128
1825	3780	1067	0006
1850	3870	1138	0-8-1903
1875	3920	1278	1754
1900	-	1522	1492
1925	-	1935	1086
1930	buckled up - concave down		
0702	0		

* no center sling

TABLE XIII-B

Data Sheet

PL 50-1/3-2
a: 10.188"
b: 32.813"
t: .229"
pits:
T-.003";B-.009"
% area: .40; 50.
Unfairness:
a: fair
b: 3/16"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L-H59241
G.F.: 1.77
PL Gages: top-type K, D43238
bottom-type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

1 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 jacks
Solder Set @ 350 psi.

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-12-0700	0	0-4-1582	0-10-1111
0800	360	1532	1082
0900	760	1468	1060
1000	1110	1403	1042
1100	1480	1333	1028
1200	1800	1246	1020
1300	2220	1145	1032
1400	2600	1005	1081
1500	2960	0825	1172
1550	3100	0696	1271
1600	3310	0522	1389
1625	3390	0432	1480
1650	3480	0308	1585
1675	-	0131	1762
1700	3620	0-3-0831	1977
1725	3710	0506	0-12-0327*
0-12-0663	0		

* buckled down - concave up.

TABLE XIII-C

Data Sheet

PL 50-1/3-3
a: 10.188"
b: 32.813"
t: .216"
pits: .010"
% area: 20
Unfairness:
a: none
b: 1/4
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58115
bottom-type K, D58110
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

7 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 jacks
Solder Set @ 300 psi.
Load Cell Edge:
Sta. 1 - 9" out from center
Sta. 2 - center
Sta. 3 - 9" in from center

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 height (in.)	Sta. 2 height (in.)	Sta. 3 height (in.)
0-12-1000	0	0-5-0729	0-4-1855	.400	.395	.360
1100	390	0762	1922			
1200	780	0807	1962	.420	.424	.380
1300	1160	0852	1999			
1400	1510	0898	0-5-1037			
1500	1910	0945	1071	.471	.486	.438
1600	2300	0987	1103			
1700	2690	1048	1127			
1800	3050	1146	1111	.496	.502	.461
1850	3280	1243	1056			
1900	3420	1482	0862	.504	.504	.463
1932	buckled down - concave up					
	500			.387	.355	.360

TABLE XIII-D

Data Sheet

PL 50-1/3-4
a: 10.188"
b: 32.813"
t: .222"
pits: T-.004;B-.008"
% area: 30; 60
Unfairness: same
a: 1/32" for 6"
b: 1/4"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type SI, D43238
bottom-type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

1 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied:
5 jacks
Set Solder @ 300 psi.

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)
0-12-0882	0	0-5-0680	0-10-1331
0950	210	0652	1316
1000	400	0622	1302
1100	800	0557	1278
1200	1190	0493	1260
1300	1540	0418	1255
1350	1760	0367	1258
1400	1980	0303	1268
1450	2180	0238	1285
1500	2390	0148	1320
1550	2590	0052	1368
1600	2770	0-4-0858	1438
1650	2980	0697	1557
1700	3150	0505	1702
1725	3250	0362	1826
1750	3330	0178	1985
1775	3400	0-3-0848	0-12-0221
1785	buckled downward (concave upward) with noise		
0-12-0777	0	gages broken on plate	

Note: buckled unsymmetrically across short dimension.

TABLE XIV-A

Data Sheet

PL 50-1/2-1
a: 10.188"
b: 21.875"
t: .222"
pits:
T-.006"; B-.015"
% area:40; 40
Unfairness:
a: fair
b: 1/32"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58115
bottom-type K, D58110
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

15 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Set solder @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1152	0	0-6-0458	0-5-1003	.276	.272	.273
1200	190	0447	0976			
1300	590	0405	0912			
1400	990	0357	0859	.262	.243	.273
1500	1390	0297	0811			
1600	1800	0229	0763			
1700	2200	0163	0722			
1800	2560	0089	0688	.298	.273	.287
1900	2980	0007	0656			
0-16-0000	3310	0-8-1925	0641			
0100	3710	1802	0642			
0200		1646	0693	.313	.292	.298
0300		1398	0842			
0400		0672	1500			
0430	buckled downward, concave upward					
1215	0					

TABLE XIV-B

Data Sheet

PL 50-1/2-2
a: 10.188"
b: 21.875"
t: .211"
pits:
T-.015"; B-.007"
% area: 40; 40
Unfairness:
a: fair
b: 1/16"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58115
bottom-type K, D58110
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

15 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Solder Set @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1226	0	0-6-0718	0-4-0538	.276	.275	.272
1300	280	0685	0506			
1400	660	0637	0458			
1500	1060	0592	0398	.284	.283	.279
1600	1420	0553	0343			
1700	1800	0508	0288			
1800	2200	0467	0227			
1900	2560	0421	0168			
0-16-0000	2900	0379	0101			
0100	3230	0340	0028	.308	.308	.312
0200	3570	0318	0-2-1952			
0300	3890	0342	1847			
0350	3990	0392	1759	.314	.317	.314
0400	4100	0472	1644			
0450	4220	0642	1435			
0500	4330	0893	1145			
0550	4420	1173	0838			
0575	4500	1362	0648			
0600	4530	1602	0360			
0625	4550	0-7-1126	0-1-0497			
0650	4500	0-7-1790	0-0-0195			
0675	buckled upward, concave down					
1525	0					

TABLE XIV-C

Data Sheet

PL 50-1/2-3	Strain Indicators: (Baldwin)	15 April 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 21.875"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .211"	PL Gages: top-type K, D58115	Load Applied: 3 jacks
pits:	bottom-type K, D58110	Solder Set @ 300 psi.
T-.012"; B-.005"	G.F.: 2.04	Load Cell Edge:
% Area: 40; 40	Pressure Gage: Blackhawk Z-720	Sta. 1 - 6" out
Unfairness:	Micrometer: Starrett #436 (1")	Sta. 2 - center
a: fair	Dial Indicator: Ames 88	Sta. 3 - 6" in
b: 1/64"	(1" @ .001") 5" extension	
Concave down		

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1525	0	0-6-0292	0-5-0811	.280	.271	.278
1600	290	0271	0761			
1700	690	0245	0692			
1800	1060	0222	0618			
1900	1450	0211	0535	.300	.297	.294
0-16-0000	1840	0206	0431			
0100	2220	0218	0320			
0200	2590	0251	0188			
0300	2940	0316	0021	.337	.350	.339
0400	3290	0420	0-3-1808			
0500	3630	0625	1496			
0550	3810	0790	1279	.362	.375	.358
0600	3980	0993	1032			
0625	4000	1143	0852			
0675	4110	1343	0589			
0685	4200	1858	0-1-1652			
1546	buckled upward, concave down					

TABLE XIV-D

Data Sheet

PL 50-1/2-4	Strain Indicators: (Baldwin)	15 April 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 21.875"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .218"	PL Gages: top-type K, D58115	Load Applied: 3 jacks
pits:	bottom-type K, D58110	Solder set @ 300 psi.
T-.009"; B-.003"	G.F.: 2.04	Load Cell Edge:
% area: 50; 40.	Pressure Gage: Blackhawk Z-720	Sta. 1 - 6" out
Unfairness:	Micrometer: Starrett #436 (1")	Sta. 2 - center
a: fair	Dial Indicator: Ames 88	Sta. 3 - 6" in
b: 1/64"	(1" @ .001") 5" extension	
Concave down		

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1542	0	0-5-0598	0-4-0211	.277	.267	.268
1600	200	0585	0182			
1700	550	0567	0108			
1800	920	0555	0034			
1900	1320	0545	0-2-1940	.302	.285	.282
0-16-0000	1680	0546	1842			
0100	2070	0563	1723			
0200	2410	0602	1578			
0300	2780	0678	1409	.336	.323	.313
0400	3100	0802	1197			
0500	3420	0990	0927			
0550	3580	1142	0742			
0600	3710	1285	0522	.341	.340	.347
0650	3880	1459	0361			
0675	3910	1563	0242			
0700	4000	1740	0005			
0725	4010	0-0-1050	0-0 1462			
0760	buckled upward	concave down				
1610	0					

TABLE XV-A

Data Sheet

PL 70-1/4-1	Strain Indicators: (Baldwin)	31 March 1955
a: 10.188"	Load Meas: Type L, H59241	Ship Structures Lab.
b: 43.750"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .158	PL Gages: top - type SI, D43238	Load Applied: 7 jacks
pits: .004"	bottom - type L, H80797	Center Sling Used
% area: 50	G.F.: 2.04	Solder set @ 350 psi.
Unfairness:	Pressure Gage: Blackhawk Z-720	
a: 1/16"	Micrometer: Starrett #436 (1")	
b: fair	Dial Indicator: Ames 88	
Concave down	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	
0-12-0259	0	0-5-1168	0-10-0282	
0300	150	1217	0190	
0350	330	1302	0052	no unfairness-support removed
0375	410	1355	0- 8-1968	creaking
0400	500	1435	1857	no unfairness
0425	610	1539	1721	
0450	710	1678	1548	
0475	800	1872	1308	
0500	900	0-6-1275	0881	no unfairness
0525	1000	1842	0195	
0545		0-7-1652	0-4-0081	ultimate buckled upward
0249	0			concave downward

TABLE XV-B

Data Sheet

PL 70-1/4-2
a: 10.188"
b: 43.750"
t: .158"
pits: .004"
% area: 50
Unfairness: same
a: 1/64"
b: 1/16"
one end
Concave up

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type SI, D43238
bottom-type L, H80797
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

31 March 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 7 jacks
Center sling used
Solder set @ 300 psi.

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	
0-12-0258	0	0-5-1198	0-10-0179	
0300	180	1172	0155	
0350	320	1139	0122	
0400	510	1111	0089	middle support not removed
0450	710	1085	0056	
0475	810	1075	0035	
0500	900	1066	0015	
0525	1000	1058	0-8-1988	
0550	1090	1053	1969	
0575	1180	1048	1943	
0600	1280	1046	1915	
0625	1350	1056	1873	
0650	1400	1139	1742	
0666	-	buckled upward with very small buckle		
0261	0	0-9-1527	0-4-1127	

TABLE XV-C

Data Sheet

PL 70-1/4-3	Strain Indicators: (Baldwin)	31 March 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 43.750"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .158"	PL Gages: top - type SI, D43238	Load Applied: 7 jacks
pits: .004"	bottom - type L, H80797	Center sling used
% area: 50	G.F.: 2.04	Solder set @ 340 psi.
Unfairness:	Pressure Gage: Blackhawk Z-720	
a: 1/32"	Micrometer: Starrett #436 (1")	
b: fair	Dial Indicator: Ames 88	
Concave up	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	
0-12-0258	0	0-5-0898	0-8-1888	
0300	170	0846	1897	
0350	320	0775	1911	fair - supports removed
0400	500	0686	1942	
0425	610	0635	1962	
0450	710	0578	1991	
0475	800	0507	0-10-0036	
0500	890	0415	0098	creaking
0525	1000	0291	0192	
0550	1090	0075	0365	
0575	1180	0-4-0478	0826	
0597	buckled	concave upward		
0258	0	-	-	

TABLE XV-D

Data Sheet

PL 70-1/4-4	Strain Indicators: (Baldwin)	1 April 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 43.570"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .158"	PL Gages: top-type SI, D43238	Load Applied: 7 jacks
pits: .004	bottom-type L, H80797	Center sling used
% area: 50	G.F.: 2.04	Solder set @ 280 psi.
Unfairness: same	Pressure Gage: Blackhawk Z-720	Top gage: 10 meg.
a: 3/64"	Micrometer: Starrett #436 (1")	ground
b: 3/8"	Dial Indicator: Ames 88	
Concave up	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	
0-12-0875	0	0-4-0573	0-10-1031	
0950	210	0513	1030	
1000	400	0455	1028	support removed
1050	580	0407	1032	
1075	680	0377	1038	
1100	780	0343	1048	
1125	880	0301	1063	fair log
1150	970	0251	1092	
1175	1060	0183	1136	
1200	1150	0078	1212	
1225	1240	0-3-0758	1429	
1248			buckled downward, concave upward	
0876	0		A-4-0365	

TABLE XVI-A

Data Sheet

PL 70-1/3-1	Strain Indicators: (Baldwin)	7 April 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 32.813"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .161"	PL Gages: top - type K, D58115	Load Applied: 5 jacks
pits: .003"	bottom - type K, D58110	Solder set @ 300 psi.
% area: 90	G.F.: 2.04	Load Cell Edge:
Unfairness:	Pressure Gage: Blackhawk Z-720	Sta. 1 - 9" out
a: fair	Micrometer: Starrett #436 (1")	Sta. 2 - center
b: 1/16"	Dial Indicator: Ames 88	Sta. 3 - 9" in
Concave down	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-12-0978	0	0-4-1518	0-5-0937	.379	.373	.406
1050	280	1485	1055	.418	.429	.428
1150	650	1341	1316			
1200	840	1163	1557	.480	.507	.490
1250	1020	0827	1991			
1275	1130	0501	0-6-1408	*.478	.524	.524
1300	1220	0-3-0912	0-7-1178			
1325	1320	0-2-0275	0-9-1502	.595	.645	.595
1334	buckled upward, concave down					
0952	0					

*segments interfere

TABLE XVI-B

Data Sheet

PL 70-1/3-2	Strain Indicators: (Baldwin)	12 April 1955
a: 10.188"	Load Meas: type L, H59241	Ship Structures Lab.
b: 32.813"	G.F.: 1.77	Bldg. 41, M.I.T.
t: .162"	PL Gages: top-type K, D58115	Load Applied: 5 jacks
pits: .002"	bottom-type K, D58110	Solder set @ 300 psi.
% area: 60.	G.F.: 2.04	Load Cell Edge:
Unfairness: same	Pressure Gage: Blackhawk Z-720	Sta. 1 - 9" out
a: 1/32"	Micrometer: Starrett #436 (1")	Sta. 2 - center
b: 1/16"	Dial Indicator: Ames 88	Sta. 3 - 9" in
Concave down	(1" @ .001") 5" extension	

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1107	0	0-6-0406	0-4-0689	.260	.229	.262
1200	380	0506	0441			
1300	740	0809	0-3-0972	.292	.263	.294
1350	950	1214	0420			
1400	1120	0-7-1247	0-1-0982	.393	.374	.380
1425	1210	0-8-1120	0-0-0712			
1449	buckled upward - fair					
1030	0	A-5-0813	B-1-0642			

TABLE XVI-C

Data Sheet

PL 70-1/3-3
a: 10.188"
b: 32.813"
t: .158"
pits: .003"
% area: 60
Unfairness: same
a: 3/64"
b: 1/8"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58115
bottom-type K, D58110
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

12 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 jacks
Solder set @ 300 psi.
Load cell Edge:
Sta. 1 - 9" out
Sta. 2 - center
Sta. 3 - 9" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1050	0	0-5-0637	0-5-0511	.294	.277	.261
1100	200	0696	0386			
1200	580	0952	0022	.341	.336	.311
1250	780	1173	0-4-0748			
1275	830	1403	0476			
1300	960	1642	0200			
1325	1030	0-6-1000	0-2-1784	.394	.407	.393
1340	1100	1357	0-2-1372			
1360	1190	1808	0818			
1375	1220	0-7-1261	0238			
1390	1260	0-8-1568	0-0-0425			
1400	1300	0-10-1242	B-7-0408			
1402	Buckled upward - loud snap					
1032	0	A-4-1128	B-1-1017			

TABLE XVI-D

Data Sheet

PL 70-1/3-4
a: 10.188"
b: 32.813"
t: .158"
pits: .003"
% area: 50
Unfairness:
a: fair
b: 1/32"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top - type K, D58115
bottom - type K, D58110
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

12 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 5 jacks
Solder set @ 300 psi.
Load Cell Edge:
Sta. 1 - 9" out
Sta. 2 - center
Sta. 3 - 9" in

Load Indicator (μ- in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1040	0	0-6-0667	0-4-1331	.224	.176	.225
1100	220	0671	1245			
1200	600	0752	1025	.291	.234	.276
1250	800	0846	0860			
1300	990	1039	0581			
1325	1080	1210	0360			
1350	1170	1477	0-3-1031	.347	.353	.347
1375	1260	1947	0458			
1390	1300	0-8-0466	0-1-1829			
1400	1340	1261	0842			
1410	1350	0-9-1683	0-0-0017			
1415	buckled upward, concave down					
1022	0	broken gages				

TABLE XVII-A

Data Sheet

PL 70-1/2-1
a: 10.188"
b: 21.875"
t: .154"
pits:
T-.006"; B-.002"
% area:50; 20
Unfairness: same
a: 1/16"
b: 1/8".
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58110
bottom-type K, D58115
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

14 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Solder set @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1121	0	0-6-0587	0-4-1625	.292	.308	.274
1200	310	0583	1522			
1300	700	0607	1362	.320	.330	.280
1350	900	0656	1249			
1400	1100	0724	1116	.322	.355	.312
1450	1290	0837	0946			
1500	1480	0985	0732			
1550	1670	1229	0418	.347	.390	.343
1575	1750	1341	0278			
1600	1850	1472	0110			
1625	1960	1618	0-2-1930	.367	.408	.363
1640	2000	1735	1781			
1650	2060	1822	1669			
1675	2140	1978	1448			
1690	2200	0-8-0077	1288			
1700	2220	0215	1077			
1725	2330	0400	0742			
1740	2390	0722	0042			
1741	buckled upward, main bend near load cell					
1088	0	0-6-0872	0-3-0842	plate torn near ballbearing		

TABLE XVII-B

Data Sheet

PL 70-1/2-2
a: 10.188"
b: 21.875"
t: .154"
pits:
T-.003"; B-.006"
% area: 20; 40
Unfairness:
a: fair
b: 3/32"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58110
bottom-type K, D58115
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

14 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Solder set @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1096	0	0-6-0276	0-6-0201	.274	.292	.257
1200	410	0217	0119			
1300	810	0137	0055	.312	.344	.305
1400	1190	0068	0-4-1985			
1500	1540	0008	1899	.337	.377	.333
1550	1750	0018	1818			
1600	1940	0110	1660			
1650	2120	0629	1100	.377	.429	.375
1675	2220	0958	0755			
1690	2280	1177	0523			
1700	2310	1267	0420			
1710	2330	1382	0293			
1725	2400	1537	0107			
1740	2420	1661	0-3-0949			
1750	2500	1766	0808	.417	.475	.430
1760	2510	1985	0407			
1774	2580	0-8-0208	0-3-0040			
1784	buckled upward, concave down					
1091	0	0-6-1022	0-3-0827			

TABLE XVII-C

Data Sheet

PL 70-1/2-3
a: 10.188"
b: 21.875"
t: .154"
pits:
T-.002"; B-.004"
% area: 10; 40
Unfairness:
a: fair
b: 1/16"
Concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58110
bottom-type K, D58115
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

14 April 1955
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Solder set @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1100	0	0-5-1199	0-5-0479	.256	.273	.265
1200	370	1181	0382			
1300	770	1187	0258			
1400	1150	1258	0067	.286	.331	.309
1500	1510	1465	0-3-1717			
1550	1710	1672	1438			
1600	1920	1930	1121	.319	.378	.344
1650	2120	0-7-0232	0749			
1675	2220	0419	0519			
1700	2320	0578	0309	.375	.410	.372
1725	2400	0850	0-2-0860			
1740	2480	1045	0460			
1750	2500	1248	0089			
1760	2540	1596	0-0-1425			
1774	buckled upward, concave down					
1109	0	0-8-0432	B-9-0771			

TABLE XVII-D

Data Sheet

PL 70-1/2-4
a: 10.188"
b: 21.875"
t: .154"
pits:
T-.003"; B-.005"
% area:
40; 5 (partial)
Unfairness:
a: fair
b: 3/32"
concave down

Strain Indicators: (Baldwin)
Load Meas: type L, H59241
G.F.: 1.77
PL Gages: top-type K, D58110
bottom-type K, D58115
G.F.: 2.04
Pressure Gage: Blackhawk Z-720
Micrometer: Starrett #436 (1")
Dial Indicator: Ames 88
(1" @ .001") 5" extension

14 April
Ship Structures Lab.
Bldg. 41, M.I.T.
Load Applied: 3 jacks
Solder set @ 300 psi.
Load Cell Edge:
Sta. 1 - 6" out
Sta. 2 - center
Sta. 3 - 6" in

Load Indicator (μ-in/in)	Gage Pressure (psig)	Top Gage (μ-in/in)	Bottom Gage (μ-in/in)	Sta. 1 (in.)	Sta. 2 (in.)	Sta. 3 (in.)
0-14-1114	0	0-5-0682	0-3-1730	.270	.288	.272
1200	300	0649	1671			
1300	680	0589	1617			
1400	1050	0537	1546	.290	.315	.283
1500	1410	0498	1448			
1550	1600	0495	1385			
1600	1800	1532	1282	.306	.341	.302
1650	2000	0689	1071			
1675	2100	0897	0857			
1700	2190	1107	0642	.336	.375	.330
1725	2280	1388	0351			
1740	2310	1562	0171			
1750	2360	1671	0052			
1760	2380	1755	0-1-1968			
1770	2410	0-6-0852	1850			
1780	2440	0939	1742			
1790	2480	1008	1652			
1800	2490	1079	1553			
1810	2480	1145	1455			
1820	2560	1212	1335			
1850	2600	1372	1005			
1875	2700	1688	0342			
1890	2700	0-7-1102	0-0-0617			
1900	buckled upward, concave down					
1142	0	A-2-1202	B-3-0065			

TABLE XIX

Modulus Data

1 July 1954
Gaucher and Rinehart

Instruments:
Huggenberger Tensometers:
#2195 G.F. = 1055
#2201 G.F. = 1064
Micrometers:
Starrett #436 0-1", 2"-3"
Load Application:
M.I.T. #202 capacity 10,000 lbs.
Hemisphere head - ESA Laboratory
Special specimen frame - Structures Laboratory

Specimen #1 l = 2.550" w = 0.842" t = 0.1875"

Load (lbs)	H #2201 Gage Reading	H #2195 Gage Reading	Load (lbs)	H #2201 Gage Reading	H #2195 Gage Reading
0	1.53	1.43	6620	0.25	0.34
520	1.36	1.41		1.49	1.53
1015	1.21	1.35	6720	1.19	1.21
1565	1.075	1.24	6775	0.86	0.80
1995	0.98	1.15	6835	0.52	0.405
2530	0.85	1.04	6895	0.26	0.03
3010	0.75	0.935		1.51	1.43
3460	0.65	0.82	6905	1.28	1.09
3980	0.56	0.70	6940	0.95	0.67
4375	0.505	0.56	6950	0.58	0.34
4645	0.45	0.495		1.52	1.58
5100	0.40	0.34	6980	1.03	1.16
5440	0.37	0.23	6965	0.24	-0.04
5900	0.33	0.04		1.54	1.46
	1.43	1.49	7035	0.63	0.51
6250	1.15	1.125	9060		
6475	0.65	0.70			

TABLE XIX (Con't.)

Specimen #2   l = 2.550"   w = 0.8425"   t = 0.1874"

Load (lbs)	H #2201 Gage Reading	H #2195 Gage Reading	Load (lbs)	H #2201 Gage Reading	H #2195 Gage Reading
0	1.45	1.54	5580	0.18	0.295
155	1.39	1.53	5845	0.15	0.265
290	1.34	1.52		1.43	1.33
720	1.24	1.43	5990	1.405	1.305
1235	1.12	1.325	6225	1.36	1.26
1720	1.00	1.21	6825	0.71	0.36
2300	0.88	1.095		1.425	1.47
2755	0.77	0.99	6845	0.61	0.465
3270	0.66	0.87	6960	0.19	-0.111
3720	0.56	0.765		1.38	1.525
4260	0.45	0.645	6985	0.59	0.67
4715	0.35	0.51	7040	0.11	0.34
5010	0.30	0.45		1.56	1.57
5170	0.26	0.39	7100	0.96	1.12
5380	0.22	0.34	7075	0.15	0.35

Specimen #3   l = 2.550"   w = 0.844"   t = 0.187"

Load (lbs)	H #2201 Reading	H #2195 Reading	Load (lbs)	H #2201 Reading	H #2195 Reading
0	1.52	1.465		1.45	1.45
485	1.39	1.375	5255	1.39	1.36
1025	1.26	1.265	5425	1.34	1.315
1575	1.14	1.135	5575	1.30	1.25
2055	1.05	1.025	5760	1.25	1.18
2635	0.95	0.865	6060	1.16	1.08
2995	0.89	0.775	6185	1.14	1.00
3605	0.77	0.585	6365	1.12	0.91
3975	0.71	0.465	6465	0.89	0.63
4535	0.61	0.265	6590	0.44	0.19
4950	0.54	0.130			

TABLE XX

Modulus Data

Instruments:
    Huggenberger Tensometers:
        #2195 G.F. = 1055
        #2201 G.F. = 1064
    Micrometers:
        Starrett #436 0-1", 2"-3"
Load Application:
    M.I.T. #201 capacity 50,000 lbs.
    Hemisphere head - ESA Laboratory
    Special specimen frame - Structures Laboratory

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Gaucher and Reed

Specimen #1   l = 2.552"   w = 0.850"   t = 0.253"

Load (lbs)	H #2195 Gage Reading	H #2201 Gage Reading	Load (lbs)	H #2195 Gage Reading	H #2201 Gage Reading
0	1.06	1.54	7570	1.55	1.10
470	1.10	1.35	8000	1.50	1.01
970	1.07	1.21	8200	-0.23	0.92
1500	1.01	1.12	8250	-0.30	0.83
1970	0.94	1.02		1.27	0.83
2430	0.85	0.94	8320	0.99	0.86
2970	0.77	0.85	8120	0.96	0.87
3570	0.67	0.75	8310	0.80	0.87
3980	0.59	0.75	8220	0.72	0.89
4440	0.51	0.74	8250	0.37	0.89
5000	0.41	0.74	8170	0.33	0.89
5410	0.34	0.72	8210	-0.07	0.87
6010	0.23	0.70		-0.25	0.87
6530	0.12	0.67		1.10	0.87
	1.60	1.27	8250	1.00	0.75
7070	1.58	1.20	8220	0.18	0.22

TABLE XX (Con't.)

Specimen #2 l = 2.552" w = 0.850" t = 0.252"

Load (lbs)	H #2195 Reading	H #2201 Reading	Load (lbs)	H #2195 Reading	H #2201 Reading
0	1.50	1.12	5500	0.71	0.09
470	1.49	0.97	6020	0.62	0.00
1030	1.43	0.85		1.28	1.30
1600	1.35	0.75	6450	1.19	1.20
2060	1.28	0.68	7130	1.05	1.06
2580	1.18	0.59	7520	0.92	0.98
3140	1.10	0.51	7840	0.72	0.91
3510	1.05	0.44	8130	0.50	0.86
3940	0.97	0.39	8120	-0.10	0.79
4400	0.89	0.27		1.42	0.75
5140	0.79	0.17	8050	0.52	0.74

Specimen #3 l = 2.552" w = 0.850" t = 0.2525"

Load (lbs)	H #2195 Reading	H #2201 Reading	Load (lbs)	H #2195 Reading	H #2201 Reading
0	1.36	1.43	5400	0.56	0.46
960	1.33	1.15	5930	0.47	0.39
1520	1.25	1.06	6460	0.35	0.29
2040	1.16	0.99	6960	0.23	0.22
2480	1.07	0.91	7450	0.13	0.15
3220	0.95	0.80	7870	0.02	0.08
3660	0.89	0.75		1.39	1.50
4000	0.84	0.70	7700	1.40	1.52
4490	0.73	0.61	7950	1.38	1.48
4950	0.65	0.53			

TABLE XX (Con't.)

Specimen #4 $l = 2.552"$ $w = 0.850"$ $t = 0.253"$

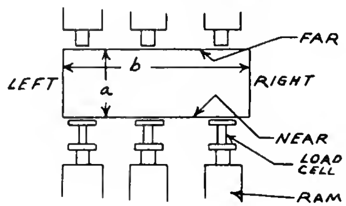
Load (lbs)	H #2195 Reading	H #2201 Reading	Load (lbs)	H #2195 Reading	H #2201 Reading
0	1.35	1.11		1.48	1.42
470	1.30	0.98	6600	1.37	1.30
940	1.26	0.90	7010	1.28	1.23
1550	1.16	0.80	7490	1.18	1.15
1990	1.09	0.73	7970	1.08	1.07
2430	1.00	0.65	8240	0.99	1.00
3060	0.90	0.54	8310	0.64	0.99
3460	0.86	0.48	8400	0.46	0.97
4030	0.76	0.38	8400	-0.30	0.96
4520	0.68	0.29		1.40	0.86
4980	0.61	0.21	8500	0.70	0.85
5440	0.53	0.12	8550	0.20	0.84
6060	0.42	0.01			

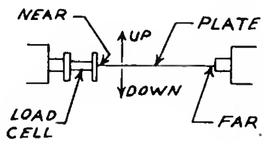
Table XVIII

Condition of Buckled Plates

Definitions: u : up; d : down
r : right; l : left
n : near; f : far
str : straight
UNS : unsymmetrical
VAR : variable

Based on observer standing behind the load cells with the plate horizontal.

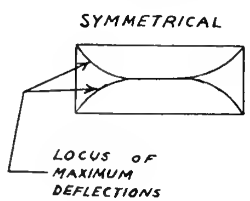


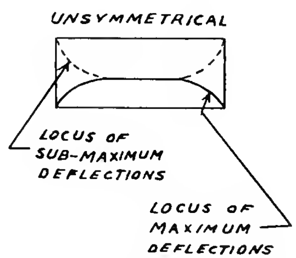


Plastic hinge: A buckle which consists of a sharp curvature normal to the plane of the plate extending from each corner to the center. The hinge is curved in the plane of the plate, with a flat curve near the center and a sharper curve near the corners.

Symmetrical plastic hinge: Equivalent sharpness of the hinge from each corner to the center. (abbreviated SPH)

Unsymmetrical plastic hinge: Sharpness of the hinge is greater towards one of the b edges. (abbreviated UPH)





* Knuckle on near b edge about 1" from ball bearing supports.
** Same as (*) with greater degree, almost torn.

PLATE	EDGES				MAXIMUM DEFLECTION (REFERRED TO b EDGE)		REMARKS
	a_r	a_l	b_n	b_f	AMOUNT	LOCATION from ℄	
40-1/4-1	3/32" d	1/16" d	3/8" u	str.	1 1/16" d	1" n	UPH(n)
2	1/16" d	1/32" d	1/8" u	1/4" u	1 1/16" d	center	SPH
3	1/32" u	1/16" u	3/16" d	1/8" d	1 1/8" u	1/2" n	SPH
4	str.	str.	3/16" d	3/16" d	1 1/8" u	center	SPH
50-1/4-4	str.	str.	1/4" d	3/16" d UNS	9/16" u	center	SPH
50-1/3-1	str.	1/32" d	3/16" d	1/16" d	1 1/4" u	1/4" n	SPH
2	1/16" d	str.	1" u *	1/8" d	1 3/8" d	center	SPH
3	1/16" d	1/16" d	7/16" u	str.	5/8" d	1/2" n	UPH(n)
4	1/16" d	1/16" d	5/16" u	1/4" u	9/16" d	1/2" n	UPH
50-1/2-1	str.	str.	1/8" u	1/8" u	5/8" d	1/4" f	SPH
2	1/16" d	str.	1 1/8 d *	1/4" u	1 1/8" u	1" n	UPH(n)
3	str.	str.	1/2" d	1/16" d	1" u	center	SPH
4	str.	str.	3/32" u	3/16" d *	5/8" u	1 1/2" f	UPH
70-1/4-1	str.	1/16" u	1/16" VAR	1/16" VAR	1 1/8 u	1/2" n	UPH
2	str.	str.	1/8" d	1/8" d	3/16" u	center	SPH
3	1/16" d	1/16" d	3/16" d	1/16" d	3/4" d	center	SPH
4	str.	1/16" d	5/16" d *	3/16" d UNS	1" d	center	SPH
70-1/3-1	str.	1/32" d	1/4" d *	1/8" u	1 3/16" u	3/4" n	UPH
2	str.	str.	1/16" u *	1/16" u	7/8" u	1" n	~SINE
3	str.	str.	— *	3/16" u	15/16" u	1/2" n	SPH
4	str.	str.	1/2" d	1/16" u	1 1/8" u	1/2" n	SPH
70-1/2-1	str.	str.	1/2" d **	1/2" u	7/8" u	1 3/4" n	UPH
2	str.	str.	1/16" u	1/2" u	1/2" u	1"-n	UPH
3	1/32" d	str	str	3/16" u	1/2" u	1 1/2" n	UPH
4	1/32" d	1/32" d	1/8" u *	1/16" u	11/16" u	center	SPH

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